# FIELD PRACTICE

DATA BOOK for
CIVIL ENGINEERS

By ELWYN E. SEELYE

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DATA BOOK FOR CIVIL ENGINEERS

# FIELD PRACTICE

ELWYN E. SEELYE

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# PREFACE

Field practice embraces the inspection and sometimes supervision of construction of engineering works by a field man who may have the background of an inspector, a designer, a clerk-of-the-works, a contractor's superintendent, or a surveyor. If the inspection and supervision are performed in accordance with modern practice, the field man merits the dignity that is implied by the title of engineer.

Modern practice for field engineers comprises extensive technological advances, many of them made within the past decade. The purpose of this volume is to enable the inspector or field engineer to brief himself as to the essentials in the inspection and supervision of the work which he is to undertake. Its purpose is also to enable him to bring to the field the basic data which he will require.

For example, sampling of material for laboratory tests should be done in accordance with certain rules. The method of taking a concrete sample for a compression or flexure test is rigidly prescribed. Any deviation from the rules will detract from the validity of the test. Hence "Rules for Sampling" are included in this book.

Certain field tests, such as the concrete slump test, the penetration of asphalt test, and soil tests, are required to control the quality of construction. These tests should be performed according to certain rules; hence, "Instructions for Field Tests."

Field engineering includes the checking of material so that size, quality, and other properties are in accordance with plans and specifications. Therefore, tables such as the detailed dimensions of steel beams and of culvert pipe are included herein to enable an inspector to identify the exact size of a steel beam or the classification of a reinforced-concrete pipe.

A whole series of special tests have been developed in connection with the science of soil mechanics. A field engineer may be required to make these tests and to furnish information concerning them. In order that he may do so, detailed information is given to determine density, grain size, Atterberg limits, optimum moisture, field shear tests, C.B.R. values, and related data.

What items should be checked by an inspector? A check list for inspectors is included for such work as concrete, bituminous paving, steel, welding, and timber. Complete information for inspecting pile driving is also given. In addition, report forms are presented so arranged that the report becomes not only a progress report but also an inspector's

checking list. This is illustrated by the steel inspector's reports, of which Part I is a list of items to be checked off by the inspector and Part II is a progress report.

The importance of surveying to field engineering has been recognized, and a section of this volume provides the data a construction surveyor requires. Under "Surveying" are stadia reduction tables, stakeout problems, curve data, railroad turnout data, earthwork tables, transit and level problems, azimuth determination, isogonic chart, instrument adjustments, tape data, plotting problems, mapping symbols, and tables of measure, trigonometric formulas, and trigonometric functions.

The identification of common building stone and timber is assisted by photographs of different types or species placed in juxtaposition to emphasize points of difference.

A few words on job power together with cuts of construction machinery are given to assist the field engineer in talking to the contractor in his own language.

ELWYN E. SEELYE

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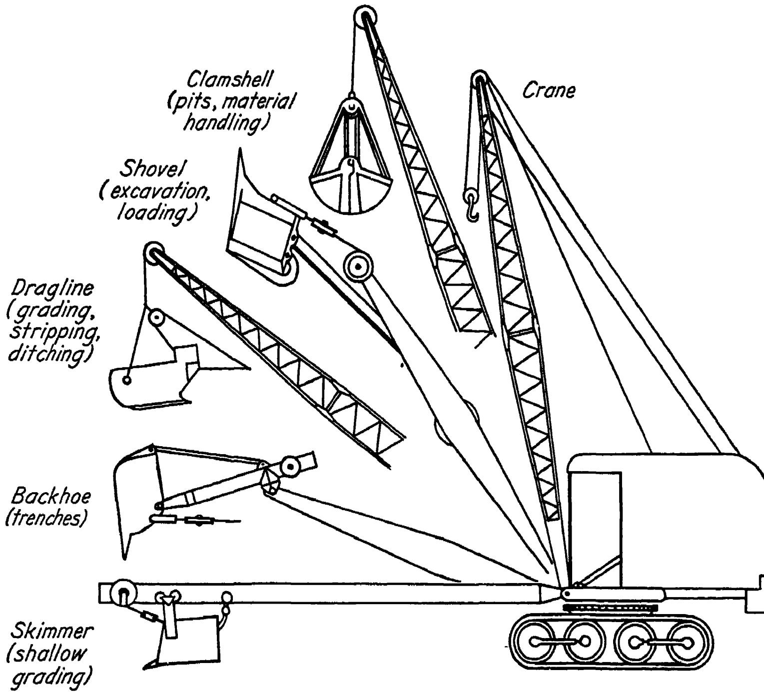
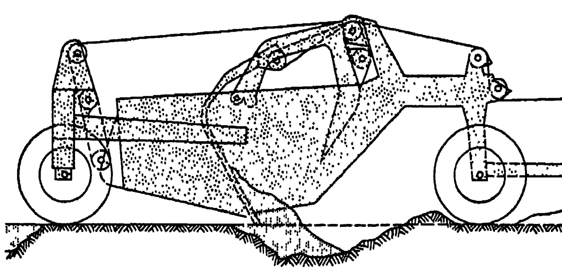



FIG. 1. Lorain crane with attachments. *Courtesy of the Thew Shovel Company.*



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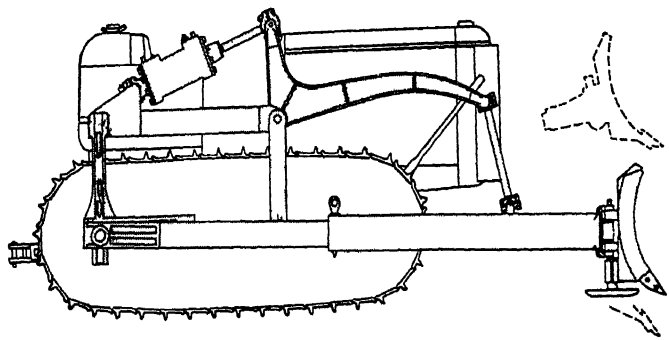

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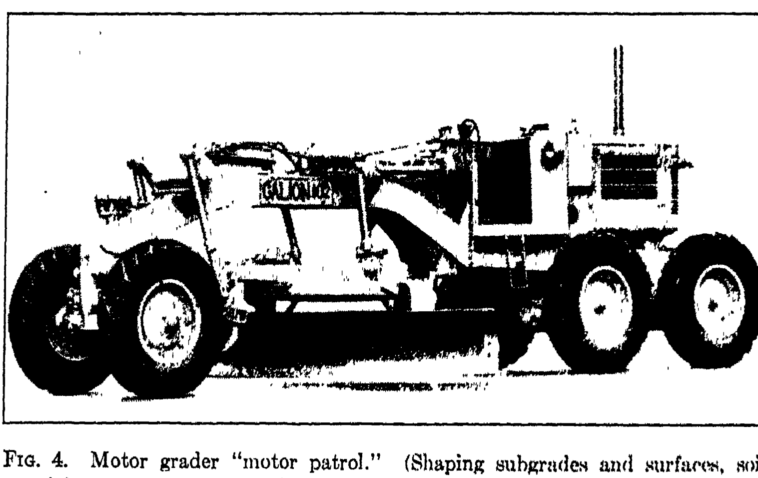

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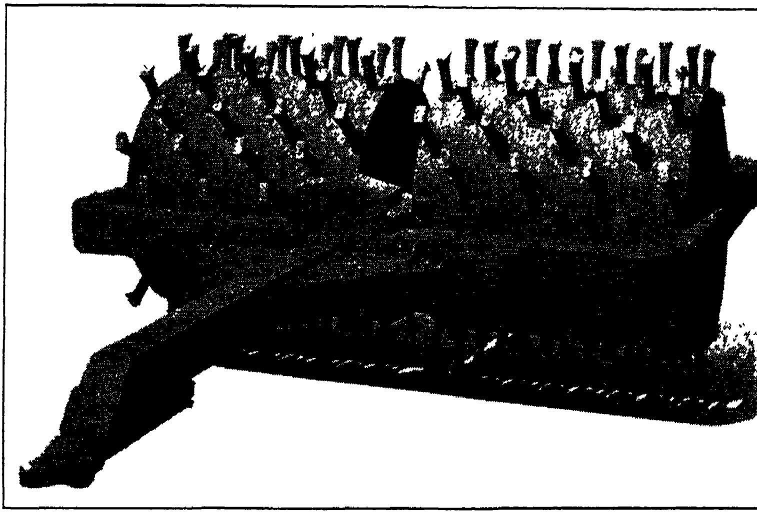

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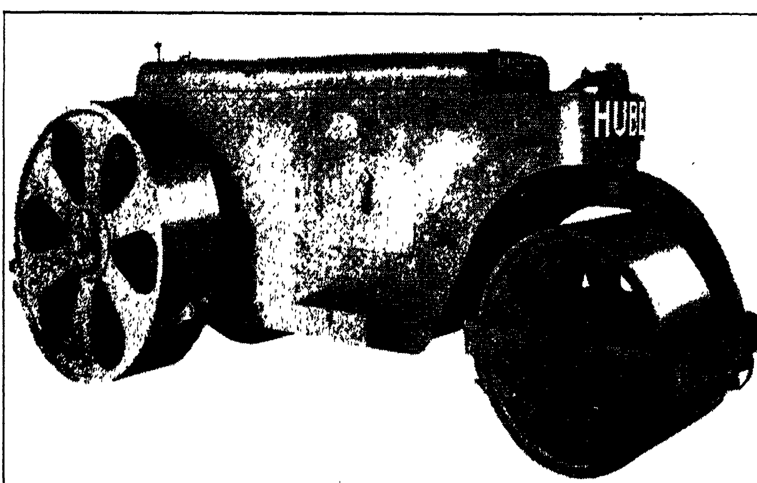


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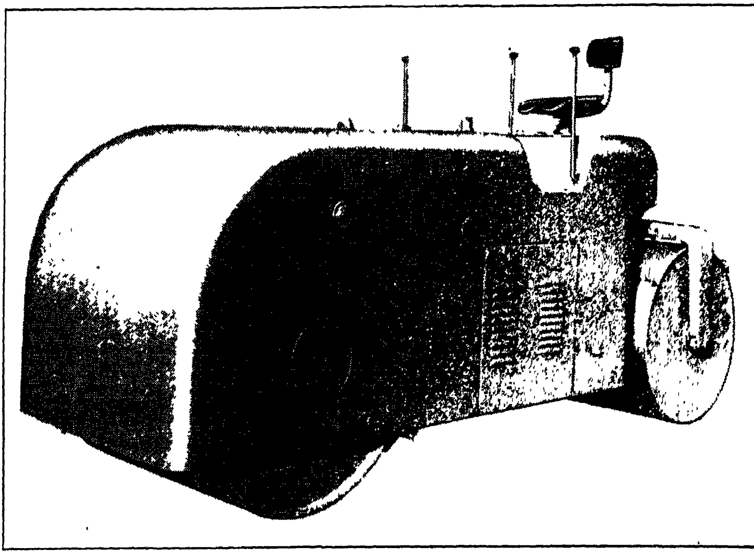

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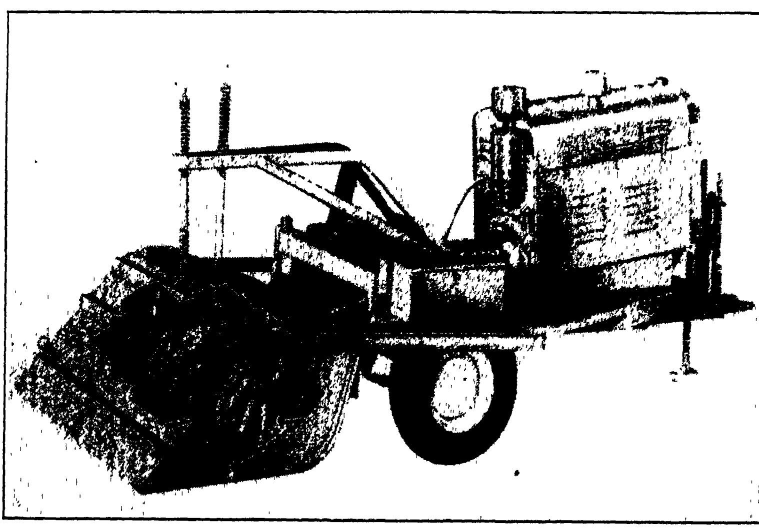

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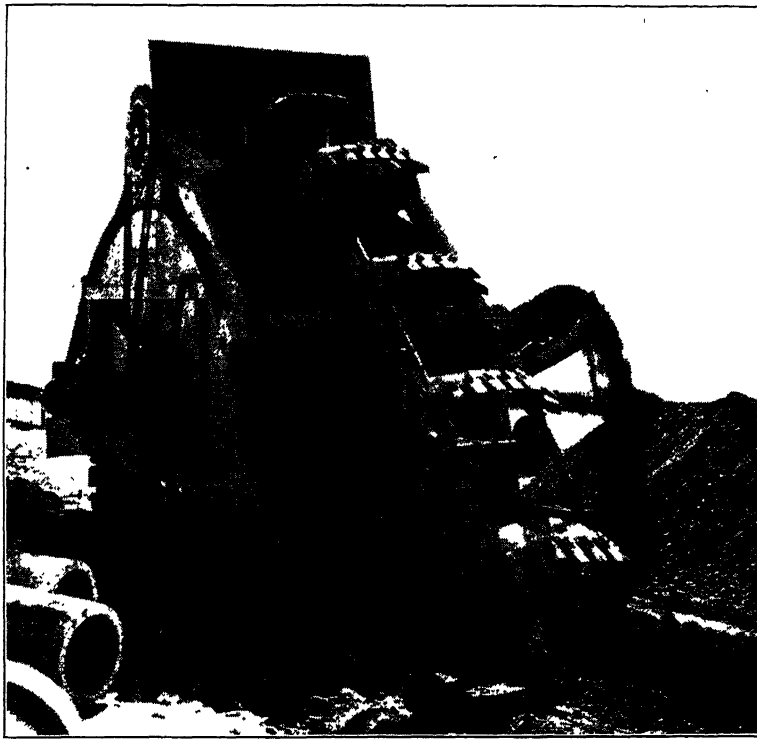

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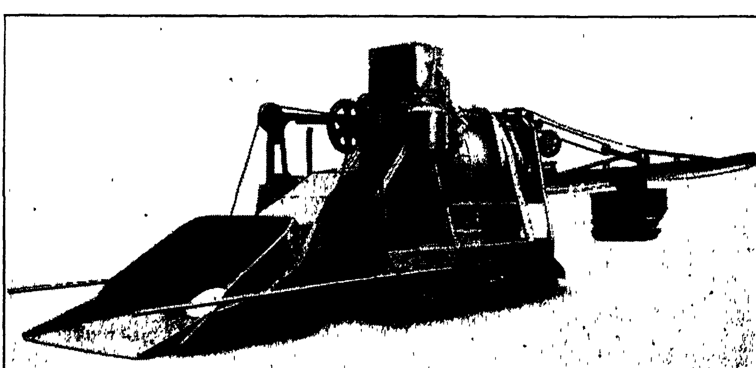

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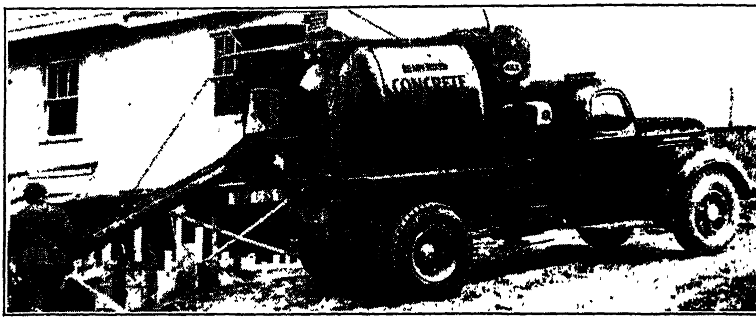

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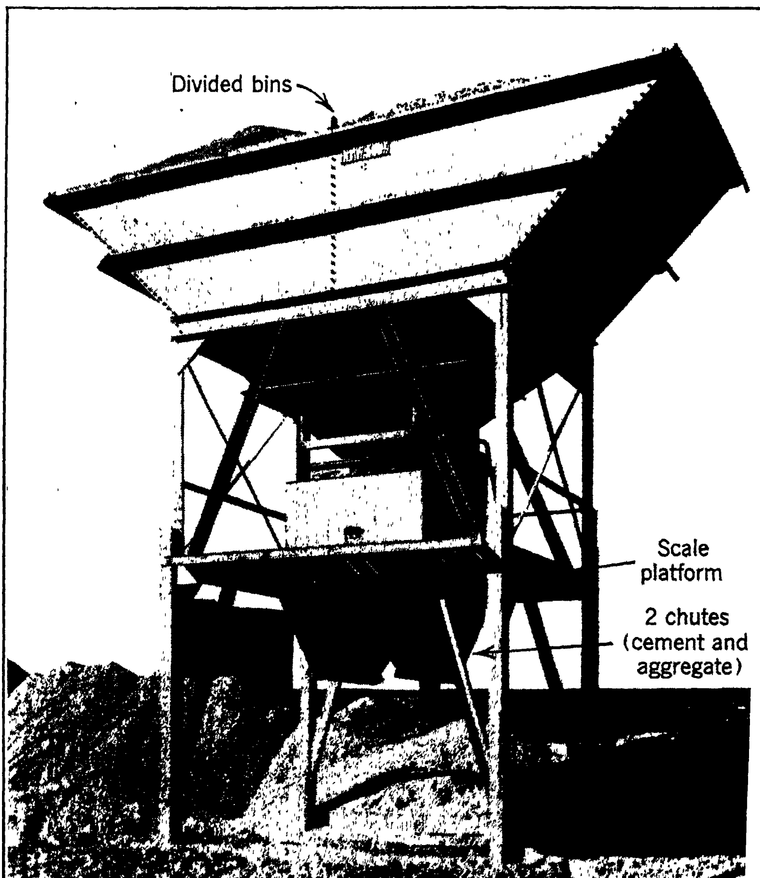


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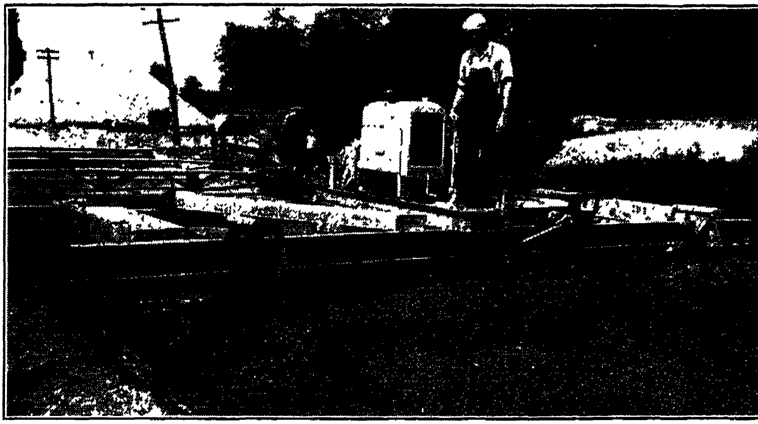

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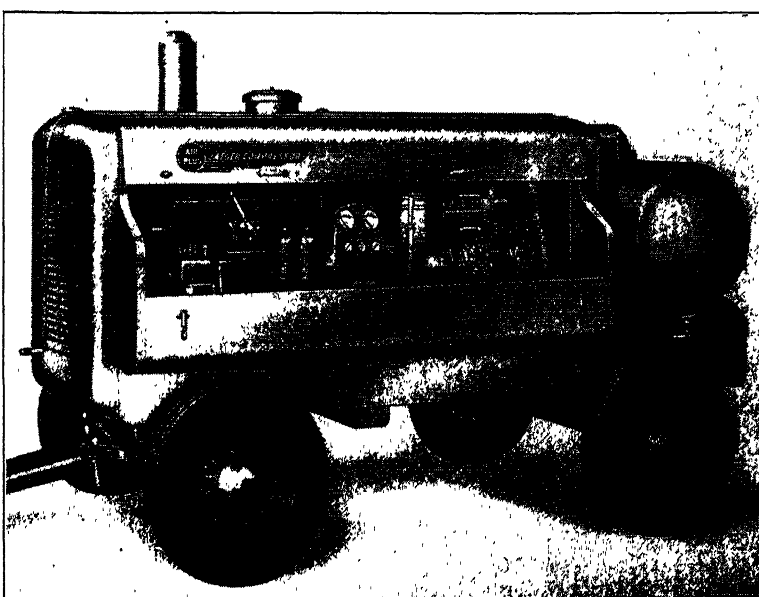


FIG. 14. Compressor. *Courtesy of the Jaeger Machine Company.*

# CONCRETE

## FIELD SAMPLING

| Material and Method | When Sampled | Size of Sample | Instructions |
|---|---|---|---|
| Cement, A.S.T.M. C-77 | Each 1600 sacks or 400 bbl. | 8 lb. min. | Sacked cement: compose sample from portions taken from 1 sack in 40. Bulk cement: sample from different locations with small scoop. Ship in container sealed airtight with paraffin. |
| Aggregates, A.S.T.M. D-75 | Each source<br>First shipment and if any change | Sand, 30 lb.<br>Stone and slag, 100 lb.<br>Gravel, 100 lb. over ½-in. size | Quarter aggregates by placing on canvas square or clean surface. Mix thoroughly. Form into conical pile. Flatten pile. Cut into 4 pie-shape parts. Discard 2 opposite quarters including dust. Remix remainder. Repeat till desired size, but not less than twice. Ship in strong, tight bag or box. |
| Steel Reinforcement, A.S.T.M. A-15, 16, or 160 | Each 10 tons<br>Each lot or shipment | 3 pieces of each size, 18 in. long min. | Wire pieces together and wrap in burlap. |
| Bar or rod mats, A.S.T.M. A-184 | Each order or each 500 mats | 2 ft. by 2 ft. | Cut sample from 2 mats in each order. Ship crated. |
| Wire fabric, A.S.T.M. A-185 and A-82 | Each order or each 75,000 sq. ft. | 2 ft. by 2 ft. | If heavy edge wire type include edge in square. Ship crated. |
| Expansion joint filler, A.S.T.M. D-545 | Each 1000 sq. ft. | 3 ft. long min. by full depth | Ship crated. Seal cork type in waterproof paper. |
| Joint sealer, A.A.S.H.O. M-18 | Each lot or shipment | 1 qt. min. | Place in friction lid can. Ship crated or boxed. |
| Curing liquids, A.S.T.M. C-156 | Each lot or shipment | 1 qt. min. | Ship in small-mouth can with cork-lined screw top. |

| | | | |
|---|---|---|---|
| Concrete test cylinders, A.S.T.M. C-31 | As specified, or 4 for each 250 cu. yd. or 2000 sq. yd. of slabs | 6 in. dia. by 12 in. high for aggregate 2 in. and under; 8 in. dia. by 16 in. high for aggregate over 2 in. | Use paraffined cardboard or metal mold. Place sample in mold in 3 equal layers, rodding each layer 25 strokes with ⅝ in. by 24 in. bullet pointed rod. Strike off top with trowel. Cover and keep moist at 60°–80° F. Do not move for 24 hr., then remove molds and paint identification on cylinder. Cure laboratory control cylinder moist at 70° F. till tested. Cure field control cylinders same as corresponding concrete. Pack in wet sawdust or burlap, and ship in strong box. |
| Concrete test beams, A.S.T.M. C-78 | 3 or 4 beams for every 2000 sq. yd. of pavement or slab | 6 in. by 6 in. by 30 in. or 36 in. | Use rigid wood or metal form (6-in. channels) lightly oiled or paraffined. Place concrete in 2 equal layers, each layer rodded 50 times per sq. ft. Spade sides and edges with trowel, and strike off top. Finish with cork float. Cover at once with damp burlap. After 24 hr. remove forms and cure moist at 60° to 75° F. for laboratory control. Paint identifying marks or symbols. Cure field control beams same as corresponding concrete. Pack in wet sawdust or burlap, and ship in strong box. |
| Calcium chloride, A.S.T.M. D-98 | Each lot or shipment | 1 qt. min. | Ship in airtight container. |
| Water, A.A.S.H.O. T-26 | Each source | 2 qt. | Ship in crated glass jar with glass stopper. |

### MARKING SAMPLES—ALL MATERIALS

Place one tag inside container, and attach one tag firmly outside. Record all shipments and data in field book. Mark tags with name and address of laboratory; date; project; contractor; engineer; sampler; quantity represented; any special test desired if other than routine; vendor's or manufacturer's name and brand name if any; location or part of structure affected; sample number; address to send report; any other pertinent information. See Fig. 17 for sample tag.

**Cement.** Railroad car number; sacked or bulk; type; mill.

**Aggregates.** Kind; quantity in source; name of plant pit or quarry, and location.

**Reinforcing.** Lot number; markings on rods.

**Test Cylinders and Beams.** Date molded; station or location in structure; mix proportions; $W/C$ ratio, gallons per sack; cement, sacks per cubic yard; slump; unit weight, pounds per cubic foot; cement brand, type, mill, and car number; type and source of aggregate, by whom made.

*Note.* Use envelope-style tags with name and address of laboratory and shipper on envelope and complete data on tag or card inside envelope tag.

## FIELD TESTING

**Slump Test for Consistency, A.S.T.M. C-143.** Use a standard slump cone made of No. 16 gage galvanized metal in the form of a frustum of a cone with the base 8 in. in diameter, the top 4 in. in diameter, and the altitude 12 in. Provide mold with foot pieces and handles.

Take 5 samples of concrete, and thoroughly mix to form test specimen. Sample from discharge stream of mixer, starting at beginning of discharge and repeating until batch is discharged. For paving concrete, samples may be taken from the batch deposited on the subgrade. Before placing concrete, dampen the cone and place on a flat, moist, non-absorbent surface. In placing each scoopful of concrete move the scoop around the top edge of the cone as the concrete slides from it, in order to insure symmetrical distribution of concrete within the cone. Fill the mold in 3 equal layers, rodding each layer with 25 strokes of a 5/8-in. $\phi$ rod 24 in. in length, bullet pointed at the lower end. Distribute the strokes in a uniform manner over the cross section of the cone and penetrate into the underlying layer. Rod the bottom layer throughout its depth. After the top layer has been rodded strike off the surface of the concrete with a trowel or board so that the cone is exactly filled. Immediately remove the cone from the concrete by raising it carefully in a vertical direction. Then measure the slump immediately by laying the 24-in. rod across the top of the cone and measuring down to the top of the sample. This is known as the slump, which is equal to 12 in. minus the height in inches, after subsidence, of the concrete specimen. The slump test should be made frequently, at least 3 or 4 times a day.

**Unit Weight of Plastic Concrete, A.S.T.M. C-138.** Use a calibrated bucket of minimum No. 11 gage metal, a 5/8-in. by 24-in. bullet-pointed rod, and a scale accurate to 0.5% of total weight tested. Capacity of bucket should be 1/10 cu. ft. for 1/2-in. maximum aggregate; 1/2 or 1/3 cu. ft. for 2-in. maximum aggregate, and 1 cu. ft. for 4-in. maximum aggregate. Place a representative sample (selected as described for slump test above) in the bucket in 3 equal layers, rodding each layer 25 strokes as described for slump test. Vibrated concrete shall be compacted in the measure by vibration. Strike off surface, taking care that measure is just level full. Weigh to nearest 0.1 lb., subtract weight of bucket, and compute net weight of concrete in pounds per cubic foot.

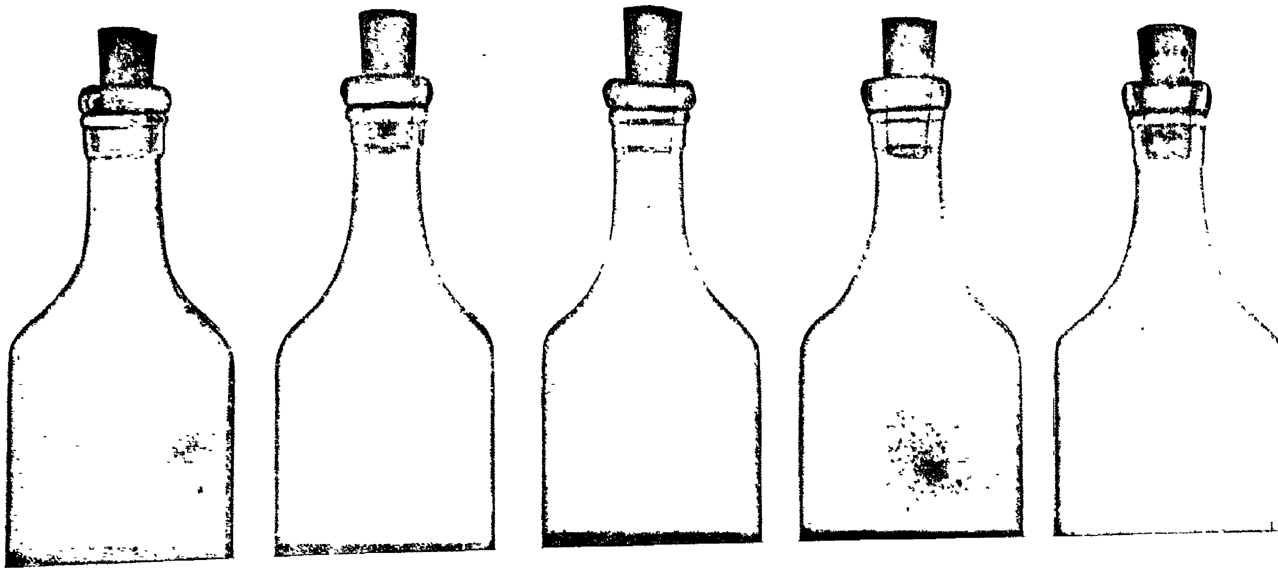
*Note.* It is suggested that the inspector carefully sample about 1 cu. ft. or more of concrete and run slump test, unit weight test, and mold cylinders and beams in one sequence of operations. Complete data will then be obtained.

PLATE I

1946 BOOK OF A.S.T.M. STANDARDS, PART II

STANDARD METHOD OF TEST FOR
ORGANIC IMPURITIES IN SANDS FOR CONCRETE

A.S.T.M DESIGNATION: C 40



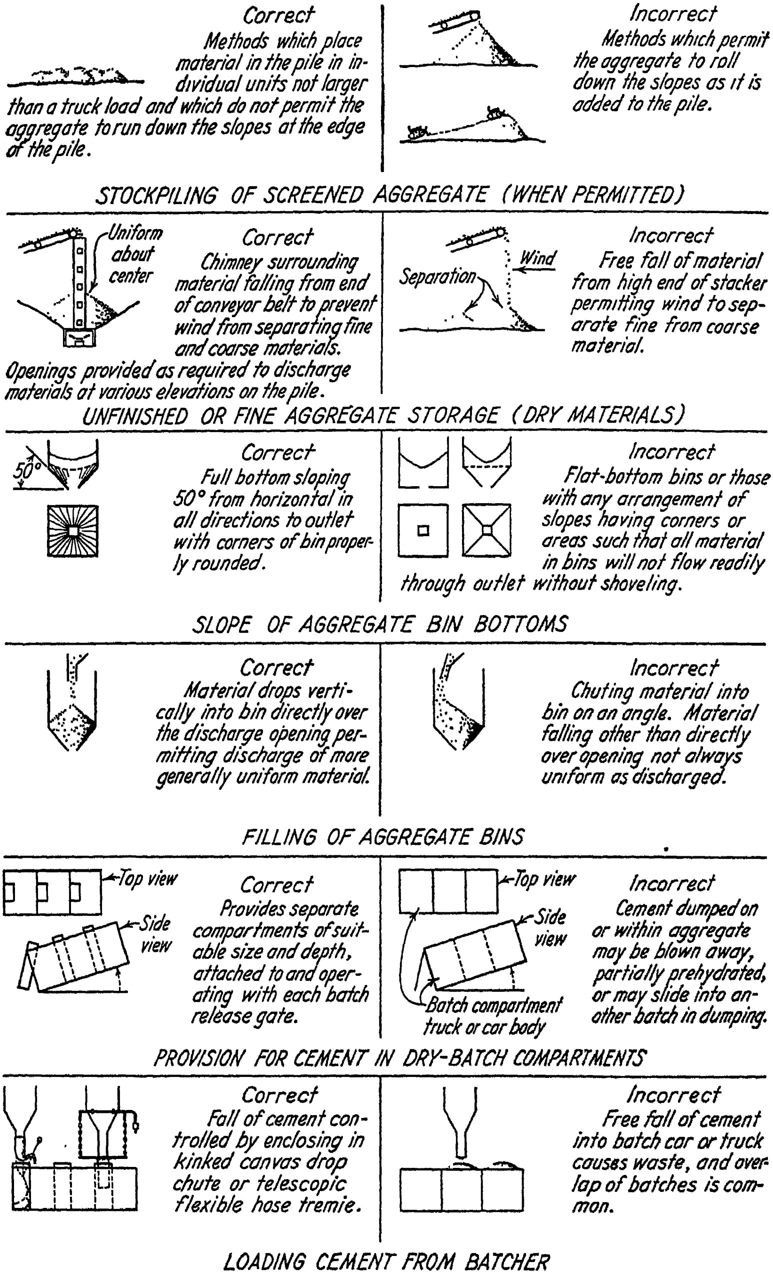



FIG. 16. Storage and handling of aggregates and cement. *From Concrete Manual, U. S. Bureau of Reclamation.*

## CONCRETE—GENERAL

### Inspectors' Equipment

Complete set of plans and specifications and approved set of reinforced-concrete working drawings.

Supply of required forms, sample tags, bags and boxes for samples.

Balance, capacity 2 kg., sensitive to 0.1 gram.

Set of square-mesh sieves of specified aggregate sizes and cleaning brush.

Fruit jar pycnometer, Chapman flask or hot plate and pan for moisture content of aggregates.

12-oz. graduate bottle and 1 lb. of sodium hydroxide (caustic soda) for colorimetric test.

Pint milk bottle for silt and clay test.

6 in. by 12 in. metal or paraffined cardboard molds for concrete test cylinders and shipping boxes for same.

Slump cone, 5/8 in. by 24 in. tamping rod, and mason's trowel.

1/3 or 1/2 cu. ft. calibrated bucket and scale for unit weight tests, when specified.

Thermometer similar to Weston All-Metal type, 0 to 180° F. for cold-weather concreting.

6-ft. rule and 50-ft. steel tape.

Plumb bob and marking keel.

Field book and pencils for records and diary.

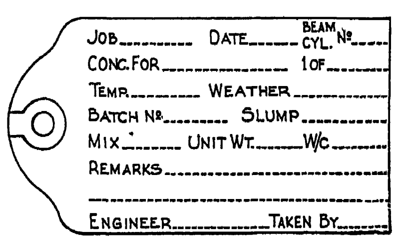



FIG. 17. Cloth tag for attaching to concrete test beams or cylinders.

## Procedure in Inspection

**Tested and Approved Materials.** Cement, aggregates, reinforcing steel, and water tested and source approved before use.

Schedule of required field tests adhered to.

Prompt shipment of samples of materials delivered at site.

Prompt reporting of field tests.

Accurate and complete daily reports and records.

Removal of rejected materials from site of work.

**Storage and Handling of Materials.** Aggregates stockpiled in 2-ft. to 4-ft. layers on mats or planking.

Aggregate segregation avoided; see Fig. 16.

Cement protected from moisture and weather.

Cement handled to avoid loss by blowing or leakage, see Fig. 16.

Reinforcing steel protected from rusting, bending, or distortion and kept free from oil or grease.

## Batch Plant Inspection

**Batching Plant.** Inspected and approved before use.

Daily check of weighing scales, accurate to tolerance of 0.004.

Use ten 50-lb. weights, check in 500-lb. increments to greatest batch weight *or* have scales checked and sealed by certified scale master.

Adequate visibility of weighing and batching.

Telltale dial or balance indicator for correct quantities in hoppers.

Positive shut-off for bulk cement.

Prompt removal of excess material in hoppers.

Protection for weighing equipment from dust or damage.

Oscillating beams normally horizontal with equal play.

Beam scale for each aggregate usually required.

**Control of Concrete.** Determine percentage of surface moisture in aggregates.

Check at least 3 times daily, or more often when slump of concrete or condition of aggregate changes.

Translate the design into batch weights, see p. 34.

Run trial batch to check on slump and unit weight of mixture.

Check on cement factor during operations to detect bulking due to voids, air entrainment, or batching inaccuracies.

Adjust batch weights to produce required cement content per cubic yard and yield of concrete per batch.

Check actual amount of cement used to concrete laid each day as check on dimensions of concrete and accuracy of batching.

*Note. The inspector should not vary the mix furnished by the laboratory without authority from the project or resident engineer.*

**Transporting Materials.** Record of batch weights and number of batches dispatched; check with mixer inspector daily.

Tight truck partitions high enough to prevent intermingling of aggregates and loss of cement. Separate cement partitions, when specified.

Required amount of cement placed in batch partitions.

Covers for batch trucks provided.

Cement carried in sacks if specified.

**Field Inspection**

**Forms.** Correct alignment and elevation.

Centering true and rigid with horizontal and diagonal bracing.

Tight enough to prevent mortar leakage.

Columns plumb, true, and cross braced.

Floor and beam centering crowned ¼ in. per 16 ft. of span.

Beveled chamfer strips at angles and corners.

Inside of forms oiled or wetted. Oil applied before placing of reinforcing.

Check installation of bolts, sleeves, inserts, and embedded items against plan details.

Check cleaning and removal of debris through temporary openings.

Check slab depths, beam and column sizes.

**Removal of Forms and Shoring.** Record of date forms poured and date forms removed.

Forms not removed until concrete is set, should ring under a hammer blow; follow job specifications.

Reshores placed after forms removed.

Forms removed carefully, damage to green concrete avoided.

Inspect surface at once after form removal. Notify superior of serious defects.

**Reinforcing Steel.** Clean and free of scale, oil, and defects. Can be rubbed down with burlap sacks or wire brushes.

Accurately fabricated to plan dimensions.

Supports rigid, metal preferable; do not allow use of rocks, brickbats, old concrete fragments, etc., to support steel.

Check minimum clear spacing between bars; 1½ diameters for round bars and 2 times side dimension for square bars.

2-in. cover for steel in exposed exterior surfaces or as specified or detailed.

Check, from working drawings, the quantity, size, placing, bending, splicing, and location of reinforcing.

Check prebent steel against bending schedule upon delivery.

**Mixing Concrete.** Mixer in good condition and kept clean of hardened concrete.

Mixer blades not worn, and drum watertight.

Check drum speed, usually 200 to 225 peripheral feet per minute.

Check mixing time frequently; should be 1 to 1½ minutes minimum.

No retempering of concrete. Mixer completely emptied before starting new batch.

Adherence to specified water content. Amount of mix water based on moisture content of aggregates obtained from batch plant inspector and correct amount added at mixer.

Check consistency; make slump test at least 2 or 3 times daily.

Check for full cement content in each batch if cement is batched at mixer.

**Ready-Mixed Concrete, Transit Mixers.** Strict adherence to job specifications.

Calibration of water-discharge mechanism plainly marked.

Error in water measurement should not exceed 1%.

Leakage in valves; should be tight when closed.

Drums should be watertight. Check specified revolutions, usually 50 to 150 allowed for mixing.

Number, arrangement, and dimensions of mixer blades checked against manufacturer's statement. Blades not worn more than 15% of stated width.

Main water tank provided against loss by leakage or surging. To discharge full volume for mixing in not more than 5 minutes.

Volume of concrete mixed not more than 58% gross volume of drum. (If concrete is central mixed and only transported in truck mixers, 80% of volume is usually allowed.)

All truck mixers inspected and approved.

Complete removal of wash water or remaining concrete after each mixer discharge.

Wash water transported in auxiliary tank with gage and watertight valve.

Adherence to specified mixing time and any restrictions on mixing en route.

Drum to be revolved during transfer of water into drum.

Adherence to correct amount of water. Inspector should approve adding additional water. If necessary to add water to discharge, dry cement should be added at required *W/C* ratio.

Concrete containing air-entraining agent not to be mixed en route.

For transit trucks the time of mixing should be from 5 minutes to 15 minutes or more, increasing with the volume of the truck and depending on the condition of the blades and whether or not it is a high dump truck.

**Placing of Concrete.** Forms inspected and approved before concreting.

Steel reinforcing in place and inspected.

Earth under footings to be undisturbed, original soil.

Rock or ledge should be well cleaned off, washed, and with no dirt or loose rock fragments.

Footings shall be free from standing water.

Avoid segregation, rehandling or flowing.

Place each unit continuously, if possible, till completed.

Spading and vibrating to maximum subsidence without segregation and next to forms and joints.

Reinforcing bars shaken to insure bond with concrete.

Accumulated water removed; concrete not placed therein.

Avoid excessive vibration and manipulation.

In thin high sections avoid having concrete stick and harden on steel and forms above placing level.

Mold required number of test cylinders each day. See p. 11.

See that wood form spreaders are knocked out and not buried as concrete is placed.

Concrete placed as close to final position as possible in continuous horizontal layers.

Concrete not placed in or under water unless as specially specified or directed by engineer.

**Construction Joints.** Avoid if possible, or place as detailed on plans.

If necessary at end of day's pour, install plumb, at right angles to plane of stress and in area of minimum shear.

Check on placing of dowels, keys, waterstops, and other details as shown on plans.

**Floors.** Check and remove laitance when concrete reaches required level. If excessive, cut down on mix water or overworking of concrete.

Finish floor as specified.

**Pumping and Conveying.** Only if approved or specified.

Equipment cleaned before and after pouring.

Continuous flow of concrete; no segregation.

**Exposed Surfaces.** Retain original surface film and form marks; do not rub.

Fins and projections removed.

Small voids filled with 1:2 mortar.

Construction joints only as detailed on plans.

Metal ties, chairs and spacers covered with 1½ in. of concrete.

**Curing Concrete.** Kept moist for 1 week minimum or sprayed with approved preparation.

Continuous saturation by sprays or wet fabric is preferred to intermittent sprinkling by hand. On vertical surfaces see that wet fabric is kept in contact with concrete.

Prompt application of curing materials as soon as possible after finishing concrete.

**Cold-Weather Concreting.** Do not heat cement. Aggregates and/or water heated to not over 175° F. No snow or frozen lumps in aggregate.

Check temperature of concrete as placed, not less than 60° F. or more than 100° F. Use immersion thermometer inserted in concrete near forms or surface.

Ice and snow removed from forms, place of deposit and reinforcement before placing concrete.

**Frost Protection.** Provided by full enclosure of concrete and temperature of not less than 60° F. maintained for 7 days or as specified. Keep humidity high in enclosure.

*Or*, by consent of engineer, provided by protecting surface with straw, hay, or fabric for 7 days. In buildings enclose story below and heat to 50° F. for 7 days.

Temperature protection gradually removed to prevent sudden freezing of concrete.

**Accelerating Admixtures** (Calcium Chloride). Use only if specified. Tested before use.

Delivered in moisture-proof bags or airtight drums.

Quantity used not over 2 lb. per sack of cement.

Dissolve 1 lb. per quart of water, and add not more than 2 qt. per sack of cement to mixing water. Subtract amount of solution from normal quantity of mixing water.

Dry calcium chloride not to be added to aggregate in mixer skip or placed in contact with dry cement.

For cold-weather placing and curing, provide same precautions as for plain cement.

**High-Early-Strength Cement.** Use only if specified. Mixing and placing same as standard cement.

Prompt finishing (delay will ruin finish).

Curing temperature maintained as specified (usually 70° F. for 2 days or 60° F. for 3 days).

**Load Tests.** May be required for faulty workmanship, violation of specification, or concrete suspected of having been frozen.

Notify superiors if necessary.

## Pay Items

Accurate record kept of all pay items in contract, such as:

Volume of concrete placed and batches wasted.

Volume of openings or embedded structures if payment for such is not made.

Amount of reinforcing steel in pounds or tons actually placed.

Number and length of extra dowels and dowel holes drilled.

Embedded items or structures.

Any other contract pay items.

## CHECK LIST FOR INSPECTORS

### CONCRETE—PAVING

#### Procedure in Inspection

It is assumed that batching has been performed and inspected; see p. 14. For transit-mix concrete, see p. 16.

**Field Inspection**

**Subgrade.** Drainage, stability, compaction. Wet down ahead of placing. Moist, not muddy.

Grade and cross section. Full depth of pavement at all points.

Check ordinates to subgrade templates and scratch boards.

**Forms.** Approved type with true face, top, and base.

Connections rigid and true.

Alignment and grade.

Staked solidly with adequate base support.

Cleaned and oiled each time used.

**Reinforcing and Joint Assemblies.** Tested and approved reinforcing steel placed to secure final position shown on drawings.

Transverse joint assemblies at correct locations staked solidly. Accurate to line and perpendicular to subgrade. Joint material tight against forms or adjacent joint.

Approved dowels, painted and greased, held rigidly parallel to surface and axis of pavement. Correctly spaced. Approved expansion caps in place.

Correctly aligned longitudinal joints with correctly spaced tie bars held securely in place, normal to joint and parallel to surface.

**Mixing and Placing Concrete.** Full cement content of batch. Empty bags and count at end of each run to check cement factor. Provide against loss of bulk cement by blowing away.

Approved mixer with accurate timing and bell. Provision to lock discharge lever until mixing time is complete. Mixer drum not loaded more than 10% above rated capacity (29.7 cu. ft. for 27-E paver).*

Full mixing time for each batch after all ingredients are in drum. Check time frequently. Allow 1 minute minimum unless otherwise specified. Check specified revolutions of drum, usually 14 to 20 r.p.m., and peripheral speed.*

* Does not apply to transit-mix concrete.

Specified slump concrete, not too harsh or too wet. Concrete workable and plastic consistency. If not specified use following slumps: ordinary batch mixer, 1½ in. to 3 in.; if vibrated, 1 in. to 1½ in.; transit mixers, 2½ in. to 3 in. Use stiffest concrete that can be molded into forms and around reinforcing bars.

Thorough compaction of concrete. Spade or vibrate against forms and existing concrete. Do not vibrate or manipulate too much.

Daily check of cement content, yield, water cement ratio, adherence to design mix, aggregates, and cement used. Check of slump and unit weight, several tests daily.

Adequate protection at hand (burlap, cotton mats, tarpaulins, etc.), for sudden rain or drop in temperature. Assembled construction joint ready to install for stoppage over 30 minutes.

Uniform amount of concrete carried ahead of strike-off. Workmen to avoid walking on soft concrete or reinforcement assemblies. Deposit concrete in final position. Do not dump on joint assemblies.

**Finishing and Curing.** Surface finished at proper time with approved tools and appliances. Systematic checking with tested straightedge.

Ordinates checked to all screeds. For parabolic ordinates, see p. 229.

Overfinishing avoided, may produce scaling. High or low spots corrected.

Good workmanship on tooling of joints and edges; specified edge rounding radius and width of tooling.

Prompt application of approved curing agents. Curing for full period specified.

Care in removing forms and bending tie bars. Do not pry against green concrete.

Ample protection from traffic until cured.

**Sealing Joints, Opening to Traffic.** Careful cleaning and sealing of joints and cracks.

Final check for surface roughness, high joints, fractured slabs, flush sealing of joints. Correction and repair as directed.

Temporary shoulder for edge protection before traffic is allowed.

Adequate structural strength (usually flexural strength of 500 to 550 p.s.i. before opening). Test beams cured same as slab and broken by cantilever, center or ⅓ point loading. (The latter is recommended.)

**Air-Entraining Cement.** Check for minimum and maximum air content; see specification. (Usually 3 to 6% of weight of a theoretical air-free mix.) Check with standard unit weight test using ⅓ or ½ cu. ft. calibrated bucket; see p. 12. Excessive loss of weight may be due to following:

Overmixing of concrete. Check ready-mix and transit mix particularly.

High sand-aggregate ratio.

High water-cement ratio.

Air pressure in mixing drum of transit mixers. Leave discharge door partly opened and vent end of drum with four ⅝ in. diameter holes kept open at all times. Report excessive air content to engineer.

**Cold-Weather Concrete**

Concrete not placed on frozen subgrade.

Aggregate and water heated to produce temperature of concrete, at placing, of 70° F. minimum and 100° F. maximum or as specified.

Curing temperature of 50° to 100° F. maintained for specified period.

No admixtures or extra cement used unless specified.

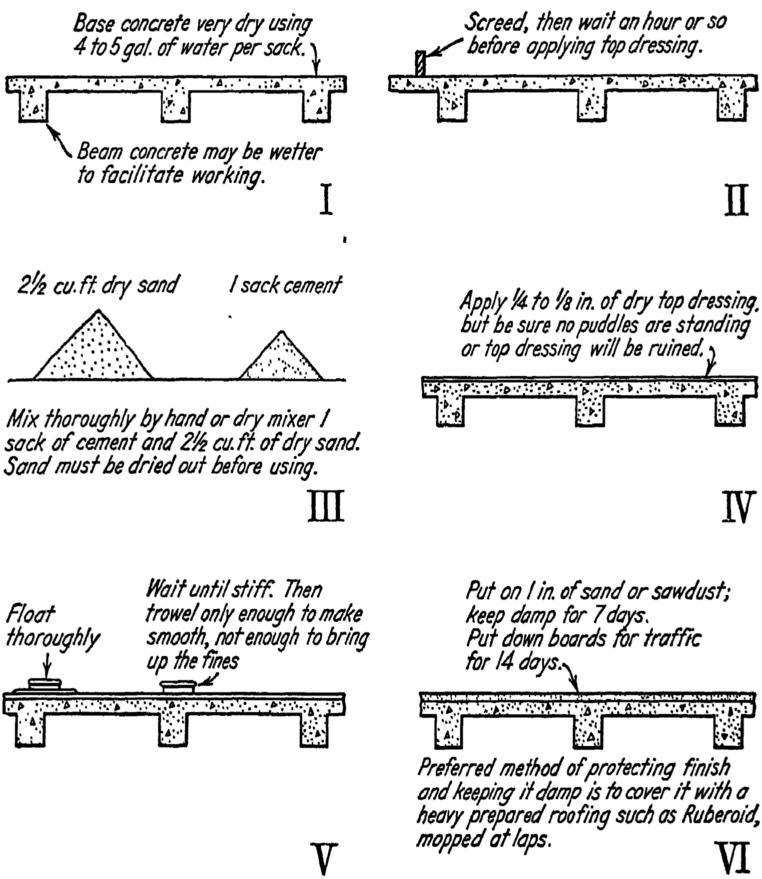



FIG. 18. Rules for construction of monolithic floor.

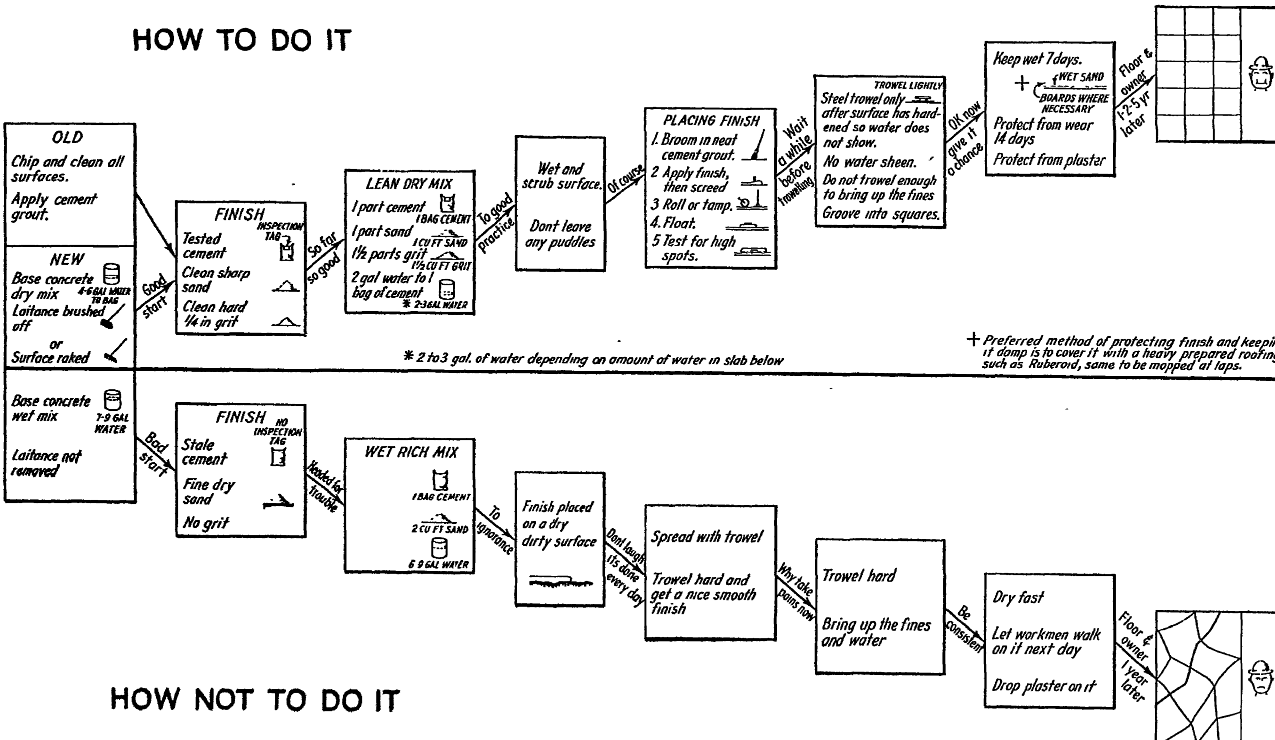



FIG. 19. Rules for construction of bonded cement finish floor.

# APPROXIMATE DATA ON CONCRETE MIXES

## TABLE 1. WATER-CEMENT RATIO (W/C) FOR VARIOUS STRENGTHS

| Water Content: *Gallons per Sack of Cement* | Water Content: *W/C by Vol. Cu. Ft. per Sack* | *W/C* Ratio by Absolute Volume | *W/C* Ratio by Weight | Strength of Concrete at 28 Days: *Compressive* | Strength of Concrete at 28 Days: *Flexural* |
|---|---|---|---|---|---|
| 5 max. | 0.668 | 1.38 | 0.444 | 5000 p.s.i. | 750 p.s.i. |
| 6 max. | 0.802 | 1.66 | 0.533 | 4000 p.s.i. | 600 p.s.i. |
| 7 max. | 0.936 | 1.93 | 0.621 | 3200 p.s.i. | 500 p.s.i. |
| 8 max. | 1.069 | 2.21 | 0.710 | 2500 p.s.i. | 450 p.s.i. |

*Note:* Strengths should be determined by trial mixes (when practicable) based on fixed *W/C*. To allow for field conditions the strength values shown in table should be reduced by about 20%.

## TABLE 2. RECOMMENDED CONSISTENCY OR SLUMP OF CONCRETE

| Type of Structure | Slump in Inches: *Max.* | Slump in Inches: *Min.* |
|---|---|---|
| Reinforced foundation walls and footings | 5 | 2 |
| Plain footings and substructure walls | 4 | 1 |
| Slabs, beams, columns, and reinforced walls | 6 | 3 |
| Pavement and mass concrete | 3 | 1 |

## TABLE 3. EXPOSED CONCRETE—MAXIMUM WATER CONTENT IN GALLONS PER SACK

| Type or Location of Concrete | Severe and Moderate Climate | Mild Climate |
|---|---|---|
| At waterline (intermittent saturation) | | |
| Sea water | 5½ | 5½ |
| Fresh water | 6 | 6 |
| Not at waterline but frequent wetting | | |
| Sea water | 6 | 6½ |
| Fresh water | 6½ | 7 |
| Ordinary exposed structures | 6½ | 7 |
| Completely submerged | | |
| Sea water | 6½ | 6½ |
| Fresh water | 7 | 7 |
| Concrete deposited through water | 5½ | 5½ |
| Pavement slabs on ground | | |
| Wearing slabs | 5½ | 6 |
| Base slabs | 6½ | 7 |

TABLE 4. RECOMMENDED PER CENT OF SAND TO TOTAL AGGREGATE

| | |
|---|---|
| Crushed stone, max. 1½-in. size | 38 to 42 |
| Crushed stone, max. ¾-in. size | 43 to 49 |
| Gravel, max. 1½-in. size | 36 to 40 |
| Gravel, max. ¾-in. size | 39 to 44 |

**Sand-Aggregate Ratio** or percentage by weight or volume of sand to total aggregate in mix should be from 33 to 45%, with extreme limits of 28 and 49%. The most economical mix will be that with lowest sand-aggregate ratio producing the desired plasticity, workability, and consistency.

## CONCRETE BATCHING

### Quantities of Materials by Fuller's Rule

**Batching by Volume—Aggregates Measured Damp and Loose.**

$$\text{Cement factor or } C = \frac{42}{1 + s + g}$$

where $C$ = sacks cement per cubic yard of concrete.
$s$ = cubic feet of sand per sack of cement.
$g$ = cubic feet of gravel or stone per sack of cement.

| | |
|---|---|
| Volume of sand required per cubic yard of concrete, or $S$ | $= 0.037Cs$ |
| Volume of gravel or stone required per cubic yard of concrete, or $G$ | $= 0.037Cg$ |
| Quantity of cement required per cubic yard of concrete, in barrels | $= \dfrac{10.5}{1 + s + g}$ |

Example. *Given:* 1:2:4 mix by volume.
*Required:* $C$, $S$, and $G$.
*Solution:*

$$C = \frac{42}{1 + 2 + 4} = \frac{42}{7} = 6 \text{ sacks cement required per cubic yard of concrete}$$

$$s = 0.037 \times 6 \times 2 = 0.44 \text{ cu. yd. of sand required per cubic yard of concrete}$$

$$G = 0.037 \times 6 \times 4 = 0.89 \text{ cu. yd. of stone or gravel required per cubic yard of concrete}$$

## QUANTITIES FOR CONCRETE MIXES *

### TABLE 5. 1-IN. GRAVEL USING *NORMAL* LEHIGH PORTLAND CEMENT

| Sacks Cement per Cu. Yd. | Concrete Consistency | $W/C$ Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight: Sand, Lb. | Gravel, Lb. | Added Water, Lb. | By Volume: Sand, Cu. Ft. | Gravel, Cu. Ft. | Added Water, Gal. | Estimated Strength, Lb. per Sq. In.: 7 Days | 28 Days |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Wet | 9.75 | 1520 | 1840 | 253 | 17.1 | 18.6 | 30.4 | 1200 | 2000 |
| 4 | Med. | 9.00 | 1550 | 1880 | 226 | 17.4 | 19.0 | 27.1 | 1400 | 2300 |
| 4 | Stiff | 8.25 | 1580 | 1920 | 200 | 17.8 | 19.3 | 24.0 | 1700 | 2700 |
| 5 | Wet | 7.80 | 1420 | 1860 | 258 | 15.9 | 18.8 | 31.0 | 1900 | 2800 |
| 5 | Med. | 7.20 | 1440 | 1900 | 231 | 16.2 | 19.2 | 27.7 | 2200 | 3200 |
| 5 | Stiff | 6.60 | 1470 | 1940 | 205 | 16.6 | 19.6 | 24.6 | 2500 | 3600 |
| 6 | Wet | 6.50 | 1320 | 1880 | 262 | 14.8 | 19.0 | 31.4 | 2500 | 3700 |
| 6 | Med. | 6.00 | 1340 | 1920 | 236 | 15.1 | 19.4 | 28.3 | 2800 | 4000 |
| 6 | Stiff | 5.50 | 1370 | 1960 | 210 | 15.4 | 19.8 | 25.2 | 3200 | 4400 |
| 7 | Wet | 5.57 | 1220 | 1890 | 267 | 13.7 | 19.1 | 32.0 | 3100 | 4400 |
| 7 | Med. | 5.14 | 1240 | 1930 | 241 | 14.0 | 19.5 | 28.9 | 3400 | 4800 |
| 7 | Stiff | 4.71 | 1270 | 1970 | 215 | 14.3 | 19.9 | 25.8 | 3700 | 5200 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

* *From Lehigh Portland Cement Company.*

**TABLE 6. 1-IN. GRAVEL USING LEHIGH *EARLY-STRENGTH* PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Consistency | W/C Ratio, Gal. per Sack | Materials per Cubic Yard — By Weight: Sand, Lb. | Gravel, Lb. | Added Water, Lb. | By Volume: Sand, Cu. Ft. | Gravel, Cu. Ft. | Added Water, Gal. | Estimated Strength, Lb. per Sq. In.: 1 Day | 3 Days | 7 Days | 28 Days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Wet | 9.75 | 1450 | 1910 | 256 | 16.3 | 19.3 | 30.7 | 500 | 1300 | 2000 | 2600 |
| 4 | Med. | 9.00 | 1480 | 1940 | 230 | 16.6 | 19.6 | 27.6 | 650 | 1600 | 2300 | 2900 |
| 4 | Stiff | 8.25 | 1510 | 1980 | 203 | 17.0 | 20.0 | 24.4 | 800 | 1900 | 2700 | 3300 |
| 5 | Wet | 7.80 | 1350 | 1920 | 261 | 15.1 | 19.4 | 31.3 | 1000 | 2100 | 2800 | 3600 |
| 5 | Med. | 7.20 | 1380 | 1960 | 234 | 15.5 | 19.8 | 28.1 | 1200 | 2400 | 3200 | 4100 |
| 5 | Stiff | 6.60 | 1400 | 2000 | 208 | 15.8 | 20.3 | 25.0 | 1400 | 2800 | 3600 | 4500 |
| 6 | Wet | 6.50 | 1250 | 1940 | 266 | 14.0 | 19.6 | 31.9 | 1500 | 2800 | 3700 | 4600 |
| 6 | Med. | 6.00 | 1280 | 1980 | 239 | 14.3 | 20.0 | 28.7 | 1700 | 3100 | 4000 | 5000 |
| 6 | Stiff | 5.50 | 1300 | 2020 | 213 | 14.6 | 20.4 | 25.6 | 1900 | 3400 | 4400 | 5500 |
| 7 | Wet | 5.57 | 1150 | 1950 | 270 | 13.0 | 19.7 | 32.4 | 1800 | 3400 | 4400 | 5400 |
| 7 | Med. | 5.14 | 1180 | 2000 | 244 | 13.2 | 20.2 | 29.3 | 2100 | 3700 | 4800 | 5800 |
| 7 | Stiff | 4.71 | 1200 | 2040 | 218 | 13.5 | 20.6 | 26.2 | 2400 | 4000 | 5200 | 6200 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

**TABLE 7. 1-IN. STONE USING *NORMAL* LEHIGH PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Consistency | $W/C$ Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight: Sand, Lb. | Stone, Lb. | Added Water, Lb. | By Volume: Sand, Cu. Ft. | Stone, Cu. Ft. | Added Water, Gal. | Estimated Strength, Lb. per Sq. In.: 7 Days | 28 Days |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Wet | 9.75 | 1760 | 1610 | 241 | 19.8 | 16.3 | 28.9 | 1200 | 2000 |
| 4 | Med. | 9.00 | 1800 | 1640 | 214 | 20.2 | 16.6 | 25.7 | 1400 | 2300 |
| 4 | Stiff | 8.25 | 1830 | 1680 | 188 | 20.6 | 16.9 | 22.6 | 1700 | 2700 |
| 5 | Wet | 7.80 | 1650 | 1640 | 246 | 18.6 | 16.5 | 29.5 | 1900 | 2800 |
| 5 | Med. | 7.20 | 1680 | 1670 | 220 | 18.9 | 16.9 | 26.4 | 2200 | 3200 |
| 5 | Stiff | 6.60 | 1720 | 1700 | 193 | 19.3 | 17.2 | 23.2 | 2500 | 3600 |
| 6 | Wet | 6.50 | 1540 | 1660 | 251 | 17.3 | 16.8 | 30.1 | 2500 | 3700 |
| 6 | Med. | 6.00 | 1580 | 1690 | 225 | 17.7 | 17.1 | 27.0 | 2800 | 4000 |
| 6 | Stiff | 5.50 | 1610 | 1730 | 198 | 18.1 | 17.5 | 23.8 | 3200 | 4400 |
| 7 | Wet | 5.57 | 1440 | 1680 | 256 | 16.2 | 16.9 | 30.7 | 3100 | 4400 |
| 7 | Med. | 5.14 | 1470 | 1710 | 230 | 16.6 | 17.3 | 27.6 | 3400 | 4800 |
| 7 | Stiff | 4.71 | 1500 | 1750 | 203 | 16.9 | 17.7 | 24.4 | 3700 | 5200 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

**TABLE 8. 1-IN. STONE USING LEHIGH *EARLY-STRENGTH* PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Consistency | W/C Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight | | | By Volume | | | Estimated Strength, Lb. per Sq. In. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sand, Lb. | Stone, Lb. | Added Water, Lb. | Sand, Cu. Ft. | Stone, Cu. Ft. | Added Water, Gal. | 1 Day | 3 Days | 7 Days |
| 4 | Wet | 9.75 | 1690 | 1680 | 244 | 19.0 | 16.9 | 29.3 | 500 | 1300 | 2000 |
| 4 | Med. | 9.00 | 1730 | 1710 | 218 | 19.4 | 17.3 | 26.2 | 650 | 1600 | 2300 |
| 4 | Stiff | 8.25 | 1760 | 1740 | 191 | 19.8 | 17.6 | 22.9 | 800 | 1900 | 2700 |
| 5 | Wet | 7.80 | 1580 | 1700 | 250 | 17.8 | 17.2 | 30.0 | 1000 | 2100 | 2800 |
| 5 | Med. | 7.20 | 1620 | 1740 | 223 | 18.2 | 17.5 | 26.8 | 1200 | 2400 | 3200 |
| 5 | Stiff | 6.60 | 1650 | 1770 | 196 | 18.5 | 17.9 | 23.5 | 1400 | 2800 | 3600 |
| 6 | Wet | 6.50 | 1480 | 1720 | 255 | 16.6 | 17.4 | 30.6 | 1500 | 2800 | 3700 |
| 6 | Med. | 6.00 | 1510 | 1760 | 228 | 17.0 | 17.8 | 27.4 | 1700 | 3100 | 4000 |
| 6 | Stiff | 5.50 | 1540 | 1800 | 202 | 17.3 | 18.1 | 24.2 | 1900 | 3400 | 4400 |
| 7 | Wet | 5.57 | 1380 | 1740 | 259 | 15.5 | 17.6 | 31.1 | 1800 | 3400 | 4400 |
| 7 | Med. | 5.14 | 1410 | 1780 | 233 | 15.8 | 17.9 | 28.0 | 2100 | 3700 | 4800 |
| 7 | Stiff | 4.71 | 1440 | 1810 | 207 | 16.1 | 18.3 | 24.8 | 2400 | 4000 | 5200 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

**TABLE 9. 2-IN. GRAVEL USING *NORMAL* LEHIGH PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Consistency | W/C Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight: Sand, Lb. | Gravel, Lb. | Added Water, Lb. | By Volume: Sand, Cu. Ft. | Gravel, Cu. Ft. | Added Water, Gal. | Estimated Strength, Lb. per Sq. In.: 7 Days | 28 Days |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Wet | 9.00 | 1410 | 2010 | 233 | 15.8 | 20.3 | 28.0 | 1400 | 2300 |
| 4 | Med. | 8.25 | 1440 | 2050 | 207 | 16.1 | 20.7 | 24.8 | 1700 | 2700 |
| 4 | Stiff | 7.50 | 1460 | 2090 | 180 | 16.4 | 21.1 | 21.6 | 2000 | 3000 |
| 5 | Wet | 7.20 | 1310 | 2030 | 238 | 14.7 | 20.5 | 28.6 | 2200 | 3200 |
| 5 | Med. | 6.60 | 1330 | 2070 | 211 | 15.0 | 20.9 | 25.3 | 2500 | 3600 |
| 5 | Stiff | 6.00 | 1360 | 2110 | 185 | 15.3 | 21.3 | 22.2 | 2800 | 4000 |
| 6 | Wet | 6.00 | 1210 | 2040 | 242 | 13.6 | 20.6 | 29.0 | 2800 | 4000 |
| 6 | Med. | 5.50 | 1230 | 2090 | 216 | 13.9 | 21.1 | 25.9 | 3200 | 4400 |
| 6 | Stiff | 5.00 | 1260 | 2130 | 190 | 14.1 | 21.5 | 22.8 | 3500 | 4900 |
| 7 | Wet | 5.14 | 1110 | 2060 | 247 | 12.5 | 20.8 | 29.6 | 3400 | 4800 |
| 7 | Med. | 4.71 | 1140 | 2100 | 221 | 12.8 | 21.2 | 26.5 | 3700 | 5200 |
| 7 | Stiff | 4.29 | 1160 | 2140 | 195 | 13.0 | 21.7 | 23.4 | 3900 | 5500 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

**TABLE 10. 2-IN. GRAVEL USING LEHIGH *EARLY-STRENGTH* PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Con-sistency | W/C Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight: Sand, Lb. | By Weight: Gravel, Lb. | By Weight: Added Water, Lb. | By Volume: Sand, Cu. Ft. | By Volume: Gravel, Cu. Ft. | By Volume: Added Water, Gal. | Estimated Strength, Lb. per Sq. In.: 1 Day | 3 Days | 7 Days |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Wet | 9.00 | 1340 | 2080 | 236 | 15.0 | 21.0 | 28.3 | 650 | 1600 | 2300 |
| 4 | Med. | 8.25 | 1360 | 2120 | 210 | 15.3 | 21.4 | 25.2 | 800 | 1900 | 2700 |
| 4 | Stiff | 7.50 | 1390 | 2160 | 184 | 15.6 | 21.8 | 22.1 | 1100 | 2200 | 3000 |
| 5 | Wet | 7.20 | 1240 | 2100 | 241 | 13.9 | 21.2 | 28.9 | 1200 | 2400 | 3200 |
| 5 | Med. | 6.60 | 1260 | 2140 | 215 | 14.2 | 21.6 | 25.8 | 1400 | 2800 | 3600 |
| 5 | Stiff | 6.00 | 1290 | 2180 | 189 | 14.5 | 22.0 | 22.7 | 1700 | 3100 | 4000 |
| 6 | Wet | 6.00 | 1140 | 2110 | 246 | 12.8 | 21.3 | 29.5 | 1700 | 3100 | 4000 |
| 6 | Med. | 5.50 | 1160 | 2150 | 220 | 13.1 | 21.8 | 26.4 | 1900 | 3400 | 4400 |
| 6 | Stiff | 5.00 | 1190 | 2200 | 193 | 13.3 | 22.2 | 23.2 | 2200 | 3800 | 4900 |
| 7 | Wet | 5.14 | 1050 | 2120 | 250 | 11.8 | 21.4 | 30.0 | 2100 | 3700 | 4800 |
| 7 | Med. | 4.71 | 1070 | 2160 | 224 | 12.0 | 21.8 | 26.9 | 2400 | 4000 | 5200 |
| 7 | Stiff | 4.29 | 1090 | 2210 | 198 | 12.3 | 22.3 | 23.8 | 2600 | 4300 | 5500 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

TABLE 11. 2-IN. STONE USING *NORMAL* LEHIGH PORTLAND CEMENT

| | | | Materials per Cubic Yard | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | By Weight | | | By Volume | | | Estimated Strength, Lb. per Sq. In. | |
| Sacks Cement per Cu. Yd. | Concrete Consistency | W/C Ratio, Gal. per Sack | Sand, Lb. | Stone, Lb. | Added Water, Lb. | Sand, Cu. Ft. | Stone, Cu. Ft. | Added Water, Gal. | 7 Days | 28 Days |
| 4 | Wet | 9.00 | 1660 | 1780 | 221 | 18.6 | 18.0 | 26.5 | 1400 | 2300 |
| 4 | Med. | 8.25 | 1690 | 1810 | 195 | 19.0 | 18.3 | 23.4 | 1700 | 2700 |
| 4 | Stiff | 7.50 | 1720 | 1850 | 168 | 19.3 | 18.7 | 20.2 | 2000 | 3000 |
| 5 | Wet | 7.20 | 1550 | 1800 | 226 | 17.4 | 18.2 | 27.1 | 2200 | 3200 |
| 5 | Med. | 6.60 | 1580 | 1840 | 200 | 17.7 | 18.6 | 24.0 | 2500 | 3600 |
| 5 | Stiff | 6.00 | 1610 | 1870 | 173 | 18.1 | 18.9 | 20.8 | 2800 | 4000 |
| 6 | Wet | 6.00 | 1440 | 1820 | 231 | 16.2 | 18.4 | 27.7 | 2800 | 4000 |
| 6 | Med. | 5.50 | 1470 | 1860 | 205 | 16.6 | 18.8 | 24.6 | 3200 | 4400 |
| 6 | Stiff | 5.00 | 1500 | 1900 | 178 | 16.9 | 19.2 | 21.4 | 3500 | 4900 |
| 7 | Wet | 5.14 | 1340 | 1840 | 236 | 15.1 | 18.6 | 28.3 | 3400 | 4800 |
| 7 | Med. | 4.71 | 1370 | 1880 | 210 | 15.4 | 19.0 | 25.2 | 3700 | 5200 |
| 7 | Stiff | 4.29 | 1400 | 1920 | 183 | 15.7 | 19.4 | 22.0 | 3900 | 5500 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

**TABLE 12. 2-IN. STONE USING LEHIGH *EARLY-STRENGTH* PORTLAND CEMENT**

| Sacks Cement per Cu. Yd. | Concrete Consistency | W/C Ratio, Gal. per Sack | Materials per Cubic Yard: By Weight | | | Materials per Cubic Yard: By Volume | | | Estimated Strength, Lb. per Sq. In. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sand, Lb. | Stone, Lb. | Added Water, Lb. | Sand, Cu. Ft. | Stone, Cu. Ft. | Added Water, Gal. | 1 Day | 3 Days | 7 Days | 28 Days |
| 4 | Wet | 9.00 | 1590 | 1840 | 224 | 17.8 | 18.6 | 26.9 | 650 | 1600 | 2300 | 2900 |
| 4 | Med. | 8.25 | 1620 | 1880 | 198 | 18.2 | 19.0 | 23.8 | 800 | 1900 | 2700 | 3300 |
| 4 | Stiff | 7.50 | 1650 | 1920 | 171 | 18.5 | 19.4 | 20.5 | 1100 | 2200 | 3000 | 3800 |
| 5 | Wet | 7.20 | 1480 | 1870 | 230 | 16.6 | 18.9 | 27.6 | 1200 | 2400 | 3200 | 4100 |
| 5 | Med. | 6.60 | 1510 | 1900 | 203 | 17.0 | 19.2 | 24.4 | 1400 | 2800 | 3600 | 4500 |
| 5 | Stiff | 6.00 | 1540 | 1940 | 177 | 17.3 | 19.6 | 21.2 | 1700 | 3100 | 4000 | 5000 |
| 6 | Wet | 6.00 | 1380 | 1890 | 234 | 15.5 | 19.0 | 28.1 | 1700 | 3100 | 4000 | 5000 |
| 6 | Med. | 5.50 | 1400 | 1920 | 208 | 15.8 | 19.4 | 25.0 | 1900 | 3400 | 4400 | 5500 |
| 6 | Stiff | 5.00 | 1430 | 1960 | 182 | 16.1 | 19.8 | 21.8 | 2200 | 3800 | 4900 | 5800 |
| 7 | Wet | 5.14 | 1280 | 1900 | 239 | 14.3 | 19.2 | 28.7 | 2100 | 3700 | 4800 | 5800 |
| 7 | Med. | 4.71 | 1300 | 1940 | 213 | 14.6 | 19.6 | 25.6 | 2400 | 4000 | 5200 | 6200 |
| 7 | Stiff | 4.29 | 1330 | 1980 | 187 | 14.9 | 20.0 | 22.4 | 2600 | 4300 | 5500 | 6600 |

*Based on Portland Cement Association Test Data. These figures are for moist curing at 70° F. For data on concrete for lower temperatures, see Table 13.*

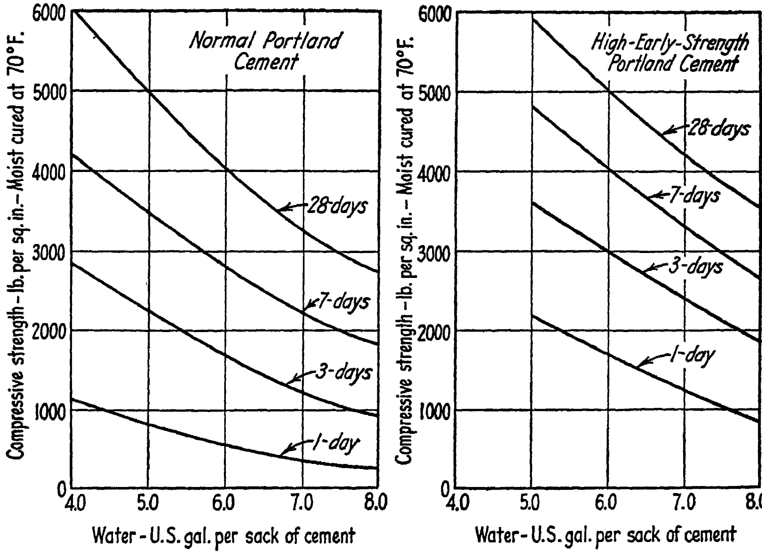



Fig. 20. Age-strength relation for normal and high-early-strength portland cements. The strengths indicated should be obtained on average construction projects where all materials, including the water, are controlled. On important work, tests should be made with the materials to be used on the project to establish job curves and fix design values.

### Approximate Quantity of Surface Water Carried by Average Aggregates * †

| | |
|---|---|
| Very wet sand | ¾ to 1 gal. per cu. ft. |
| Moderately wet sand | about ½ gal. per cu. ft. |
| Moist sand | about ¼ gal. per cu. ft. |
| Moist gravel or crushed rock | about ¼ gal. per cu. ft. |

### Approximate Absorption of Aggregates *

| | |
|---|---|
| Average sand | 1.0 per cent by weight |
| Pebbles and crushed limestone | 1.0 per cent by weight |
| Trap rock and granite | 0.5 per cent by weight |
| Porous sandstone | 7.0 per cent by weight |
| Very light and porous aggregate may be as high as | 25 per cent by weight |

* *From Portland Cement Association.*

† The coarser the aggregate, the less free water it will carry.

## MISCELLANEOUS DATA

### TABLE 13. % OF 70° MOIST-CURED COMPRESSIVE STRENGTH *NORMAL* PORTLAND CEMENT

| Placed and Cured at | 4½ Gal. per Sack | | | | 6 Gal. per Sack | | | | 9 Gal. per Sack | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 d. | 3 d. | 7 d. | 28 d. | 1 d. | 3 d. | 7 d. | 28 d. | 1 d. | 3 d. | 7 d. | 28 d. |
| 60° F. | 68% | 78% | 82% | 83% | 65% | 74% | 79% | 82% | 61% | 71% | 78% | 78% |
| 50° F. | 28% | 50% | 60% | 61% | 22% | 43% | 52% | 59% | 14% | 36% | 51% | 51% |

### % OF 70° MOIST-CURED COMPRESSIVE STRENGTH *EARLY-STRENGTH* PORTLAND CEMENT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60° F. | 72% | 88% | 94% | 94% | 70% | 78% | 88% | 93% | 70% | 85% | 88% | 94% |
| 50° F. | 38% | 72% | 80% | 88% | 34% | 64% | 75% | 84% | 32% | 66% | 73% | 85% |

*Based on "Temperature Effects on Compressive Strengths of Concrete," Timms and Withey, A. C. I. Journal, Vol. VI, No. 2.*

## CONCRETE BATCHING COMPUTATIONS

### Translating Design Mix into Batch Weights, Example

Given by laboratory:

Design mix by proportional weights (saturated surface dry aggregates):

| | Parts by Weight |
|---|---|
| Cement | 1 |
| Sand | 1.84 |
| Stone (fine) | 2.00 |
| Stone (coarse) | 1.80 |
| Water ($W/C$ ratio by weight) (4.8 gal. per sack) | 0.426 |
| Mix parts, total | 7.066 |

| | |
|---|---|
| Apparent (absolute) specific gravity of sand (without voids) saturated surface dry | 2.63 |
| Apparent (absolute) specific gravity of stone (without voids) saturated surface dry | 2.63 |
| Apparent (absolute) specific gravity of cement (without voids) saturated surface dry | 3.10 |
| Required slump | 2 in. to 2½ in. |

Determined by field test:

| | |
|---|---|
| Surface moisture in sand by weight | 4% |
| Surface moisture in stone by weight | 1% |

Constants:

| | |
|---|---|
| Weight of cement per sack | 94 lb. |
| Loose volume of cement per sack | 1 cu. ft. |
| Weight of water per gallon | 8.345 lb. |
| Volume of water per gallon | 7.5 cu. ft. |
| Weight of water per cubic foot | 62.5 lb. |

Computation of weight of each material required per sack of cement:

| | | Pounds |
|---|---|---|
| Cement | $1 \times 94 =$ | 94.00 |
| Sand | $1.84 \times 94 =$ | 172.96 |
| Fine stone | $2.00 \times 94 =$ | 188.00 |
| Coarse stone | $1.80 \times 94 =$ | 169.20 |
| Water | $4.8 \times 8.345$ or $.426 \times 94 =$ | 40.00 |
| Total weight of materials per sack of cement | $=$ | 664.16 |

Computation of yield of concrete per sack of cement:

| | | Solid Volume, Cu. Ft. |
|---|---|---|
| Cement | $\dfrac{94.00}{3.10 \times 62.5} =$ | 0.49 |
| Sand | $\dfrac{172.96}{2.63 \times 62.5} =$ | 1.05 |
| Fine stone | $\dfrac{188.00}{2.63 \times 62.5} =$ | 1.14 |
| Coarse stone | $\dfrac{169.20}{2.63 \times 62.5} =$ | 1.03 |
| Water | $\dfrac{40.00}{1 \times 62.5} =$ | 0.64 |
| Theoretical yield of concrete per sack of cement | $=$ | 4.35 |

Theoretical unit weight of concrete per cubic foot $= \dfrac{664.16}{4.35} = 152.7$ lb.

Theoretical cement content per cubic yard or cement factor $= \dfrac{27}{4.35} = 6.2$ sacks

Assuming that sacked cement is being used, batch weights are computed to utilize an even number of sacks as illustrated for a 6-sack batch. *Note.* Volume of concrete is usually not allowed to exceed 10% of rated capacity of mixer, and so a 6-sack batch in this case is selected for a 27-E paving mixer as theoretical yield for 6-sack cement = $4.35 \times 6 =$ 26.1 cu. ft. of concrete. See Table 14 for batch weights.

**TABLE 14. COMPUTATION OF BATCH WEIGHTS FOR A 6-SACK BATCH**

| Material | Parts by Weight Specified | Percentage of Each Aggregate to Total Aggregate | Batch Weights Surface Dry Aggregates 6-Bag Batch, Lb. | Surface Moisture by Test % | Surface Moisture by Test Lb. | Batch Weights Including Surface Moisture 6-Bag Batch, Lb. |
|---|---|---|---|---|---|---|
| Cement | 1 | | 94 × 6 = 564 | | | 564 |
| Sand | 1.84 | 32.6 | 564 × 1.84 = 1038 | 4 | 0.04 × 1038 = 42 | 1038 + 42 = 1080 |
| Stone, fine | 2.00 | 35.5 | 564 × 2.00 = 1128 | 1 | 0.01 × 1128 = 11 | 1128 + 11 = 1139 |
| Stone, coarse | 1.80 | 31.9 | 564 × 1.80 = 1015 | 1 | 0.01 × 1015 = 10 | 1015 + 10 = 1025 |
| Water | 0.426 | | 564 × 0.426 = 240 | | Total = 63 | 240 − 63 = 177 |
| Total batch weights | | | 3985 | | | 3985 |

177 ÷ 8.345 = 21.2 gal. of water to be added at mixer

Resulting batch weights in last column should be posted at scales.
Adjust to required slump if necessary, but do not increase water/cement ratio.

**Check of Cement Factor during Operations, Example.**

*Given:*

Total weight of materials per sack of cement = 664.16 lb.
Actual weight of 1 cu. ft. of concrete by unit weight test of freshly mixed sample = 152.5 lb.

*Computations:*

$$\frac{\text{Weight of 1-sack batch } 664.16}{\text{Unit weight of concrete } 152.5} = 4.35 \text{ cu. ft. yield per sack.}$$

Actual cement factor = 27 ÷ 4.35 = 6.2 sacks per cu. yd.

As the yield and cement factor check theoretically, no adjustment is necessary. (The air content of freshly mixed concrete made with normal portland cement is usually 0.5 to 1.0% and does not usually affect cement factor or yield enough to warrant adjustment.)

This check with normal portland-cement concrete is made to determine actual yield and cement factor when the cement factor may be running off as determined by the daily check of sacks used.

Actual sacks of cement used each day should be checked against theoretical quantity as follows: The volume of concrete is computed by dimensions. Required quantity of cement in sacks = theoretical cement factor × cubic yards of concrete. EXAMPLE. *Given:* 1000 cu. yd. of concrete and cement factor = 6.2; cement used should be 6200 sacks. Overrun of 1½% usually allowed. Underrun usually due to one or more of the following:

1. Concrete laid deficient in width and depth; check and correct.
2. Excess of water or aggregate; check and correct.
3. Errors in batching or proportioning; check and correct.
4. Volume of concrete increased by voids; check and correct.

*Air-Entraining Cement*

When air-entraining portland cement is used, the volume of concrete is increased by the void content resulting from entrainment of air in the mix. The total yield must be determined in order to check with specification requirements.

It is desirable, and usually required, that the amount of entrained air shall be not less than 3% nor more than 6% by volume. For example, a normal portland cement mix producing a yield of 27.0 cu. ft. and requiring 6.2 bags of cement would, if air-entraining portland cement is substituted without further changes, increase the yield to approximately 28.1 cu. ft. if 4% air is entrained, in which case the cement factor would be reduced to 5.95 bags per cu. yd.

Specifications generally require that the same cement factor (yield of concrete) be maintained as for normal cement use. It is therefore necessary that other ingredients, usually sand and water, be reduced by such

amount that the same yield is secured. Other reasons for such adjustment are to maintain proper consistency, workability and freedom from excess mortar not required.

The amount of air-entrainment may be determined by comparing the actual weight of the fresh concrete with its air-free weight. Then the percentage of air (gravimetric method) is:

$$\left(\frac{\text{Diff. in wt.}}{\text{Air-free wt.}}\right) 100 = \% \text{ air}$$

If, in the above case, the actual unit weight in field is 144.0 and the air-free weight is 150.0 lb., then the percentage of air by above formula is:

$$\frac{(150 - 144)}{150} 100 = 4\%$$

In order to maintain correct yield the total batch weight for use with air-entraining portland cement is adjusted for trial purposes as follows:

Reduce sand by an amount equal to 3% of the total weight of all aggregates.

Reduce water by ¼ gal. per bag of cement.

Measure unit weight of fresh concrete and divide into total batch weight for determining yield, air-entrainment, and cement factor.

The air-entrainment should be within the range of 3 to 6% in order to secure best results. Make any further adjustment necessary in water and sand and also in coarse aggregate, if desirable, to keep entrained air within this range and maintain desired cement factor.

Use following computation (from batch given above):

| | | | Absolute Volume, Cu. Ft. |
|---|---|---|---|
| Cement | $\frac{94}{3.10 \times 62.5}$ | = | 0.49 |
| Sand | $\frac{172.96 - .03(530.16)}{2.63 \times 62.5}$ | = | 0.957 |
| Fine stone | $\frac{188}{2.63 \times 62.5}$ | = | 1.14 |
| Coarse stone | $\frac{169.2}{2.63 \times 62.5}$ | = | 1.03 |
| Water | $\frac{40 - 2.09}{62.5}$ | = | 0.606 |
| Air (if adjustments in aggregate and water are correct) | | = | 0.127 |
| Yield | | = | 4.35 |

$$\frac{\text{Batch weight, 1 sack}}{\text{Unit weight by test}}\ \frac{646.17}{148.6^*} = 4.35 \text{ cu. ft. yield per bag of cement.}$$

Cement factor = 27 ÷ 4.35 = 6.2 bags per cu. yd.
Sand-aggregate ratio 100(0.957) ÷ (3.127) = 30.6%.

## CONCRETE REINFORCEMENT

### TABLE 15. STANDARD STYLES OF AMERICAN ELECTRICALLY WELDED MESH

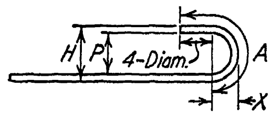
| Spacing of Wires in Inches | | American Steel & Wire Co. Gage No. | | Sect. Area per Foot of Fabric (Sq. In.) | |
|---|---|---|---|---|---|
| *Long.* | *Trans.* | *Long.* | *Trans.* | *Long.* | *Trans.* |
| 2 | 16 | 1 | 7 | 0.377 | 0.018 |
| 2 | 16 | 2 | 8 | .325 | .015 |
| 2 | 16 | 3 | 8 | .280 | .015 |
| 2 | 16 | 4 | 9 | .239 | .013 |
| 3 | 16 | 2 | 8 | .216 | .016 |
| 2 | 16 | 5 | 10 | .202 | .011 |
| 3 | 16 | 3 | 8 | .187 | .015 |
| 2 | 16 | 6 | 10 | .174 | .011 |
| 3 | 16 | 4 | 9 | .159 | .013 |
| 2 | 16 | 7 | 11 | .148 | .009 |
| 4 | 16 | 3 | 8 | .140 | .015 |
| 3 | 16 | 5 | 10 | .135 | .011 |
| 4 | 16 | 4 | 9 | .120 | .013 |
| 3 | 16 | 6 | 10 | .116 | .011 |
| 4 | 16 | 5 | 10 | .101 | .011 |
| 3 | 16 | 7 | 11 | .098 | .009 |
| 4 | 16 | 6 | 10 | .087 | .011 |
| 3 | 16 | 8 | 12 | .082 | .007 |
| 4 | 16 | 7 | 11 | .074 | .009 |
| 4 | 12 | 8 | 12 | .062 | .009 |
| 4 | 12 | 9 | 12 | .052 | .009 |
| 4 | 12 | 10 | 12 | .043 | .009 |
| 4 | 12 | 12 | 12 | .026 | .009 |
| 6 | 6 | 7 | 7 | .049 | .049 |
| 4 | 4 | 4 | 4 | .120 | .120 |
| 4 | 4 | 6 | 6 | .087 | .087 |

See pp. 58 and 59 for gage data.

* This is an assumed unit weight for purpose of this example. Actually, the unit weight may be higher or lower than this, in which event further adjustments of water or sand or also coarse aggregate must be made in order to maintain the desired cement factor and at the same time secure the necessary weight loss to insure proper air-entrainment.

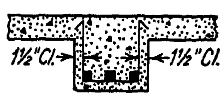
## TABLE 16. PROPERTIES OF REINFORCING BARS AND HOOK DIMENSIONS

Method of hooking bars as recommended by A.C.I.




| Size | Area | Perimeter | Wt. per Lin. Ft. | P | H | X | A |
|---|---|---|---|---|---|---|---|
| 1/4″ φ | 0.05 | 0.79 | 0.167 | 1 1/4″ | 1 3/4″ | 7/8″ | 3 3/8″ |
| 3/8″ φ | 0.11 | 1.18 | 0.376 | 1 7/8″ | 2 5/8″ | 1 3/8″ | 5″ |
| 1/2″ φ | 0.20 | 1.57 | 0.668 | 2 1/2″ | 3 1/2″ | 1 3/4″ | 6 3/4″ |
| 1/2″ □ | 0.25 | 2.00 | 0.850 | 2 1/2″ | 3 1/2″ | 1 3/4″ | 6 3/4″ |
| 5/8″ φ | 0.31 | 1.96 | 1.043 | 3 1/8″ | 4 3/8″ | 2 1/8″ | 8 3/8″ |
| 3/4″ φ | 0.44 | 2.36 | 1.502 | 3 3/4″ | 5 1/4″ | 2 5/8″ | 10″ |
| 7/8″ φ | 0.60 | 2.75 | 2.044 | 4 3/8″ | 6 1/8″ | 3″ | 11 3/4″ |
| 1″ φ | 0.79 | 3.14 | 2.670 | 5″ | 7″ | 3 1/2″ | 1′ 1 3/8″ |
| 1″ □ | 1.00 | 4.00 | 3.400 | 5″ | 7″ | 3 1/2″ | 1′ 1 3/8″ |
| 1 1/8″ □ | 1.27 | 4.50 | 4.303 | 5 5/8″ | 7 7/8″ | 3 7/8″ | 1′ 3 1/8″ |
| 1 1/4″ □ | 1.56 | 5.00 | 5.313 | 6 1/4″ | 8 3/4″ | 4 3/8″ | 1′ 4 3/4″ |

## TABLE 17. MINIMUM BEAM WIDTHS IN INCHES *




| Size of Bar | No. of Bars in Single Layer of Reinforcement 2 | 3 | 4 | 5 | 6 | 7 | 8 | Add for Each Additional Bar |
|---|---|---|---|---|---|---|---|---|
| 1/2″ φ | 6″ | 7 1/2″ | 9″ | | | | | 1 1/2″ |
| 1/2″ □ | 6 1/2″ | 8″ | 10″ | | | | | 1 3/4″ |
| 5/8″ φ | 6″ | 8″ | 9 1/2″ | 11″ | 12 1/2″ | | | 1 5/8″ |
| 3/4″ φ | 6 1/2″ | 8 1/2″ | 10 1/2″ | 12″ | 14″ | | | 1 7/8″ |
| 7/8″ φ | 7″ | 9″ | 11 1/2″ | 13 1/2″ | 16″ | 18″ | 20″ | 2 3/16″ |
| 1″ φ | 7 1/2″ | 10″ | 12 1/2″ | 15″ | 17 1/2″ | 20″ | 22 1/2″ | 2 1/2″ |
| 1″ □ | 8″ | 11″ | 14″ | 17″ | 20″ | 23″ | 26″ | 3″ |
| 1 1/8″ □ | 8 1/2″ | 12″ | 15″ | 18 1/2″ | 22″ | 25 1/2″ | 28 1/2″ | 3 3/8″ |
| 1 1/4″ □ | 9″ | 12 1/2″ | 16 1/2″ | 20″ | 24″ | 27″ | 31 1/2″ | 3 3/4″ |

* Where specially anchored bars are used, haunch width may be narrowed.

**TABLE 18. AREA OF STEEL PER FOOT OF WIDTH**

| Bar | Spacing of Bars | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size | 4″ | 4½″ | 5″ | 5½″ | 6″ | 6½″ | 7″ | 7½″ | 8″ | 8½″ | 9″ | 9½″ | 10″ | 10½″ | 11″ | 11½″ | 12″ |
| ¼″φ | 0.15 | 0.13 | 0.12 | 0.11 | 0.10 | 0.09 | 0.08 | 0.08 | 0.07 | 0.07 | 0.07 | 0.06 | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 |
| ⅜″φ | 0.33 | 0.29 | 0.26 | 0.24 | 0.22 | 0.20 | 0.19 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.13 | 0.12 | 0.11 | 0.11 |
| ½″φ | 0.59 | 0.52 | 0.47 | 0.43 | 0.39 | 0.36 | 0.34 | 0.31 | 0.29 | 0.28 | 0.26 | 0.25 | 0.23 | 0.22 | 0.21 | 0.20 | 0.20 |
| ½″□ | 0.75 | 0.67 | 0.60 | 0.55 | 0.50 | 0.46 | 0.43 | 0.40 | 0.37 | 0.35 | 0.33 | 0.32 | 0.30 | 0.29 | 0.27 | 0.26 | 0.25 |
| ⅝″φ | 0.92 | 0.82 | 0.74 | 0.67 | 0.61 | 0.57 | 0.53 | 0.49 | 0.46 | 0.43 | 0.41 | 0.39 | 0.37 | 0.35 | 0.33 | 0.32 | 0.31 |
| ¾″φ | 1.33 | 1.18 | 1.06 | 0.96 | 0.88 | 0.82 | 0.76 | 0.71 | 0.66 | 0.62 | 0.59 | 0.56 | 0.53 | 0.51 | 0.48 | 0.46 | 0.44 |
| ⅞″φ | 1.80 | 1.60 | 1.44 | 1.31 | 1.20 | 1.11 | 1.03 | 0.96 | 0.90 | 0.85 | 0.80 | 0.76 | 0.72 | 0.69 | 0.66 | 0.62 | 0.60 |
| 1″φ | 2.36 | 2.09 | 1.88 | 1.71 | 1.57 | 1.45 | 1.35 | 1.26 | 1.18 | 1.11 | 1.05 | 0.99 | 0.94 | 0.90 | 0.86 | 0.82 | 0.78 |
| 1″□ | 3.00 | 2.67 | 2.40 | 2.18 | 2.00 | 1.85 | 1.71 | 1.60 | 1.50 | 1.41 | 1.33 | 1.26 | 1.20 | 1.14 | 1.09 | 1.04 | 1.00 |
| 1⅛″□ | 3.80 | 3.37 | 3.04 | 2.76 | 2.53 | 2.34 | 2.17 | 2.02 | 1.90 | 1.79 | 1.69 | 1.60 | 1.52 | 1.45 | 1.38 | 1.32 | 1.27 |
| 1¼″□ | 4.69 | 4.17 | 3.75 | 3.41 | 3.13 | 2.89 | 2.68 | 2.50 | 2.34 | 2.21 | 2.08 | 1.97 | 1.87 | 1.79 | 1.70 | 1.63 | 1.56 |

## LOAD TESTS

*Permanent measurable deflections are a sign of weakness.*

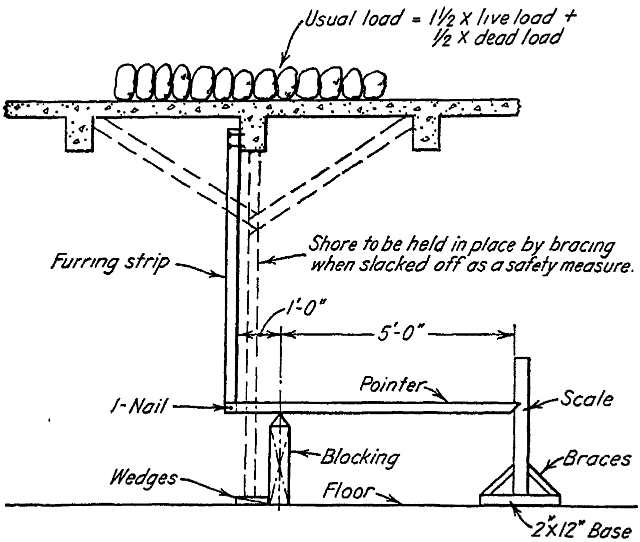



FIG. 21. Standard deflection magnifier for load tests.

*Note.* When the expense of safety shoring is too great, men conducting a load test may be protected by using a roller as a test load, the roller being towed from some safe distance. Level shots to measure deflection can be taken.

____________________
Engineer

## REPORT ON CONCRETE STRUCTURES

### Field Inspection

*(Short Form)*

Report No. ________ Date ________

Job ____________________ Temp. ________

Reported to ____________________

### Work Inspected

| | Location or Station | Reinforcement and Forms | Concrete |
|---|---|---|---|
| Footings | | | |
| Columns | | | |
| Beams | | | |
| Slabs | | | |
| Walls | | | |

Aggregate inspected ____________________

Slump tests made ____________________

Test cylinders made ____________________

Frost protection checked ____________________

____________________
Inspector

____________________
Engineer

# REPORT ON CONCRETE STRUCTURES

## Field Inspection

*(Long Form)*

Report No. __________ Date __________

Job ____________________ Temp. __________

Reported to ____________________

### Work Inspected

| | Location or Station | Reinforcement and Forms | Concrete | Yardage | |
|---|---|---|---|---|---|
| | | | | Today | Total to date incl. |
| Footings | | | | | |
| Columns | | | | | |
| Beams | | | | | |
| Slabs | | | | | |
| Walls | | | | | |

Cement: tested and sealed __________

Coarse aggregate: size, appearance, cleanliness, soundness __________

Fine aggregate: grading, silt content by bottle sediment test __________

Forms: dimensions, oil, cleanliness, tightness __________

Reinforcement: inserts, recesses, concrete coverage for protection __________

Slump tests: cylinders and/or test beams __________

Construction joints __________

Mixing: proportioning, water content, time of mixing __________

Concrete placing, vibration or rodding __________

Finishing __________

Protection vs. frost __________

Curing __________

Form stripping and reshoring __________

____________________
Inspector

Engineer

REPORT ON CONCRETE TEST SPECIMENS *

FIELD DATA
*To be filled in by maker of specimens*

| | | | |
|---|---|---|---|
| Project, name and symbol: | | | District: |
| No. specimens in shipment: | Type of specimens: ☐ Cylinders: ☐ Cores: ☐ Beams: Diameter, in. | | Symbols: |
| Date placed: | Date extracted (*cores*): | Date shipped: | Monolith extracted from: |
| Cubic yards represented: | Mixture (*by weight*): | Slump, in.: | Sand. Total aggregate ratio % by vol. |
| Theoretical unit wt.: lb./cu. ft. | Actual Unit Weight: lb./cu. ft. | Calculated air content: % | Net actual *W/C*: gal./bag |
| Admixture type and amount: % | | *Cement Factor* Theoretical: bags/cu. yd. | Actual: bags/cu. yd. |

*Cement*

| | |
|---|---|
| Cement Spec. SS-C- Type: | Brand: |
| Mill name and location: | Car number: |

*Type and Source of Aggregate*

| | |
|---|---|
| Fine aggregate: | Coarse aggregate: |

By Whom Prepared (*Inspector*)

LABORATORY DATA
*To be filled in by laboratory*

| Specimen No. | Date Tested: | ☐ Flexural Strength, p.s.i. ☐ Compressive Strength, p.s.i. | | | | |
|---|---|---|---|---|---|---|
| | | 7-Day | 14-Day | 28-Day | 90-Day | 180-Day |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| | |
|---|---|
| Date specimens received: | Temperature of specimens when received: °F. |

Remarks:

* *From War Department Corps of Engineers, North Atlantic Division.*

______________________
Engineer

## REPORT ON CONCRETE TEST BEAMS

| No. | Date Cast | Loca-tion | Date Shipped | Flexural Strength | | Remarks | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 7-day | 28-day | Slump | Den-sity | Percentage of Air Voids |
| | | | | | | | | |
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______________________
Inspector

______________________
Engineer

REPORT ON CEMENT ANALYSES *

Date ____________

Client ______________________________ Report ____________

Project ______________________________

Mill ______________________________

| Specific Surface | Time of Set | | Soundness | Tensile Strength 1–3 | | | | Ignition Loss | Insoluble Residue | Magnesia | Sulfuric Anhydride |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | | 1 | 3 | 7 | 28 | | | | |
| | | | | | | | | | | | |

Reported to:

The above tests do / do not fulfill A.S.T.M. Spec. ________ Type ________

______________________
Inspector

* *Adapted from Haller Engineering Associates, Inc.*

Engineer

CEMENT SHIPPING REPORT *

Gentlemen:

Shipments of portland cement indicated have been mill inspected and sealed for your account.

| Car Number | Seal | Contents Bbl. | Bin | Brand | Destination |
|---|---|---|---|---|---|
| | | | | | |

Reported to:

Inspector

* *Adapted from Haller Engineering Associates, Inc.*

## CHECK LIST FOR INSPECTORS

### MASONRY

**Inspectors' Equipment**

Complete set of plans, specifications, approved samples and shop drawings.

Set of sieves of specified sand sizes.

Plumb bob and line.

6-foot rule.

**Procedure in Inspection**

Prepare and ship samples of brick, concrete block, clay tile, sand lime bricks, cement, and sand lime to laboratory for test.

Perform sieve tests on sand for mortar at site.

Inspect brick. Discard underburned brick (sometimes called salmon brick), which is pale in color if a red brick. Compare brick with specifications. Face brick can best be checked from approved sample.

See that joints are according to specification.

If the engineer has built up a sample of wall, see that this is followed.

Check thickness of joints, type of pointing, and mortar against specifications.

Check lime against lime memorandum on pp. 49 and 50, particularly as to length of time after slaking.

Do not permit laying of brick in weather cold enough to freeze mortar. See specifications.

Check bonding of brickwork.

In warm weather, dry brick to be wetted.

All beds and vertical joints to be full without voids.

No voids permitted in interior of wall.

Check wall for plumbness and level courses.

All flashings, weep holes, and sills built in as required by plans and specifications.

Lift brick up that are laid. There should be sufficient suction to lift mortar with them.

### LIME FOR MORTAR AND MASONRY

Lime is produced in two forms as follows:

1. High-calcium quicklime, which is sent to the job in powdered form of two different kinds: pulverized or granular, labeled as quicklime. One has no particular advantage over the other.

This lime is slaked by adding water similar to the method of preparing lump lime, and must be allowed to age 3 to 7 days.

One ton of quicklime will produce approximately 80 cu. ft. of stiff lime putty.

2. Hydrated lime, which is lime containing water in chemical combination. It is a calcium hydroxide and comes on the job labeled hydrated masons' lime. This lime also comes in two different kinds: (*a*) Ordinary hydrated lime. This product should be soaked in water for not less than 24 hours before using. (*b*) Pressure hydrated lime. This lime can safely be put in the mixer without any treatment whatever. It is used exactly the same as cement.

## IDENTIFICATION OF BUILDING STONE

Granite is a coarse-grained, hard, igneous rock in which the different minerals give a speckled appearance.

True granite contains the following elements:

Quartz—a clear, hard crystal.

Feldspar, which looks like a yellowish tooth.

Hornblende—hard, black, shiny.

Mica—thin, flaky, transparent.

Pyrite, which looks like a yellowish metal.

Bastard granite contains some but not all of these crystals.

Both granites are excellent building materials although too much pyrite might cause stain and a possible breaking down of the stone by weathering.

Gneiss may be either sedimentary or igneous rock which has been metamorphosed, that is, compressed and worked under sufficient pressure and heat so that the structural changes were by plastic flow rather than by cracking.

In gneiss, the interlocking minerals are for the most part visible to the naked eye. The gneisses are banded. Gneiss is a satisfactory building material.

Gneisses merge into schists as the texture becomes finer.

Schists with a large percentage of mica are known as mica schists. As a building material they are subject to cleavage.

Trap rock is heavy, dark, and igneous. The origin of its name is steps as it tends to break into steplike blocks. Trap rock is an excellent building material.

Basalt is a dark igneous rock ranging from dark gray to black. Its texture is very fine. Basalt is an excellent building material.

Marble is a metamorphosed limestone and in its broken state shows shiny, smooth, crystalline surfaces. It is vulnerable to dissolving in certain atmospheres or water. Its hardness is medium. Marble may be made from either calcitic or dolomitic limestone. The dolomitic limestone does not effervesce with dilute acid. Marble has excellent durability and workability for buildings.

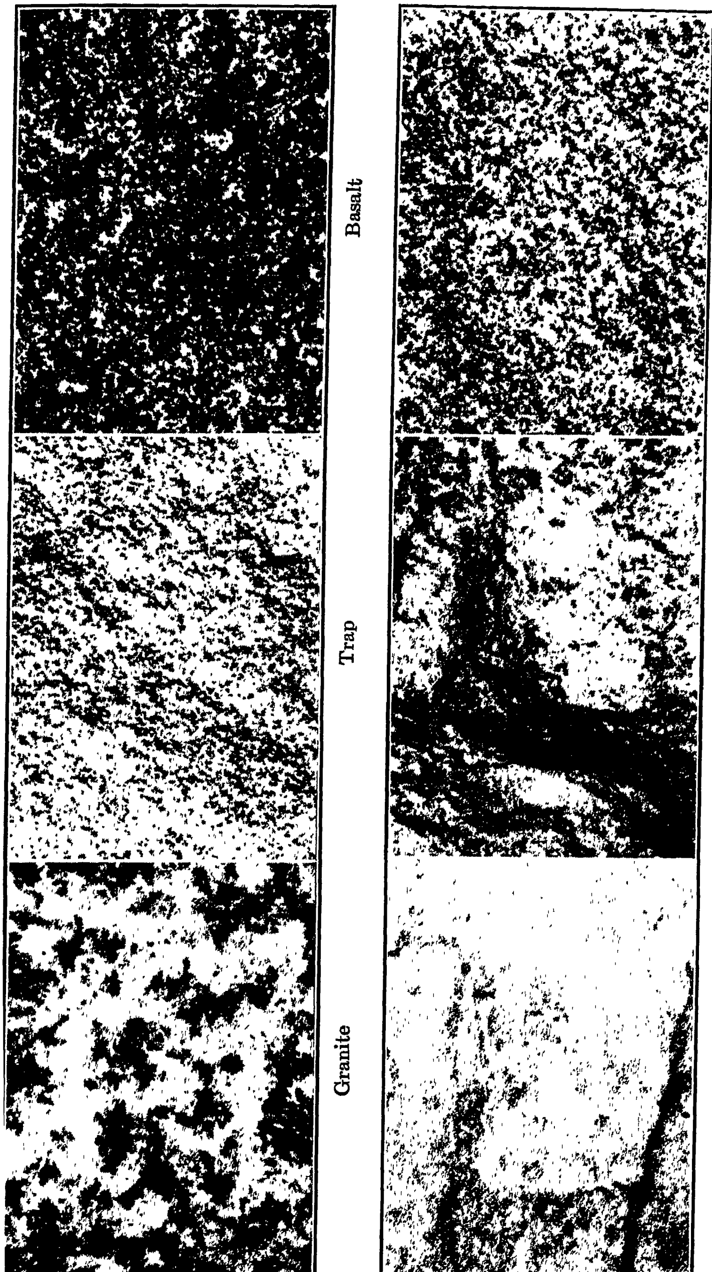



Fig. 21A.

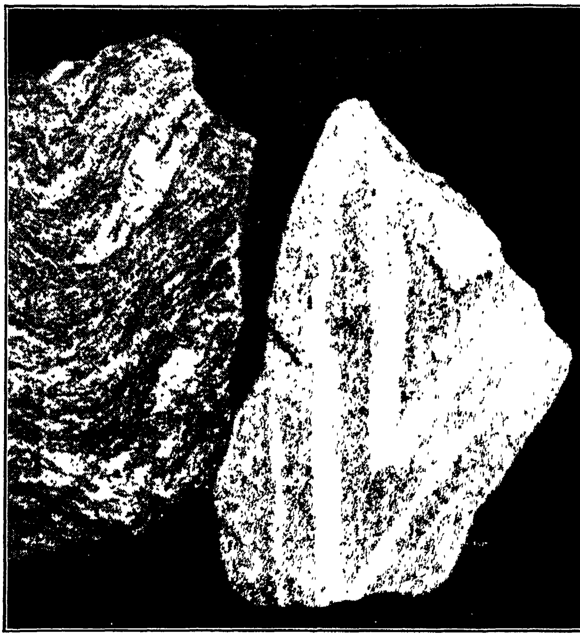



FIG. 21B.

Limestone is calcium carbonate rock of sedimentary origin. It is somewhat vulnerable and may be distinguished from magnesium carbonate limestone by the fact that it effervesces under a dilute solution of acid, which is not the case with the dolomite. Individual grains cannot be distinguished. Limestone is soft, easily worked, and a reasonably good building stone but vulnerable.

Sandstone, as its name implies, is made up of sand cemented with silica or lime. In general, the grains are distinguishable. Its reliability as a building material can be ascertained only after investigation; for instance, brownstone is a sandstone which has not always proved reliable.

Slates are metamorphosed shale and have cleavage planes along which the stone is split for commercial purposes. These cleavage planes occur at an angle to the bed planes. Slates are a satisfactory building material, particularly for roofs.

Shale comes from silt and clay and occurs in beds which tend to "shale" off. It is softer than limestone and unreliable as a building material.

Caution: Sedimentary stone should be laid on natural beds.

Definition: Porphyritic texture means a texture in which the larger minerals appear to be embedded in a matrix.

# STRUCTURAL STEEL

## CHECK LIST FOR INSPECTORS

### STRUCTURAL STEEL

*The following is based on the assumption that steel has been inspected in shop. If this has not been done, steel should be completely checked against shop details and for correct sections.*

**Inspectors' Equipment**

Complete set of erection plans and specifications.

Details should not be necessary unless shop inspection was not made or unless necessary to show special field connections.

Steel tape.

6-ft. rule.

Plumb bob.

Rivet-testing hammer.

Steel handbook.

Necessary coveralls, helmet, gloves, etc.

Calipers, gages, etc.

**Procedure in Inspection**

Members should be checked for damage in shipment, such as bent plates, connection angles or members themselves, and condition of paint. This checking should be done before erection so that damaged pieces may be rejected or rectified by straightening or reinforcing.

Anchor bolts should be checked as to size, location, elevation, and plumbing.

Base plates and grillages should be checked for correct work, level, and proper grouting. In general, they should be leveled up so as to carry load direct to foundations or walls.

Columns resting on base plates, grillages, or girders and column splices should be checked for proper bearing of milled surfaces. Where column sections change in nominal section and milled fillers are used, they should be carefully inspected.

Minor corrections may be made with steel shims.

Plumbing of columns should be checked to specified tolerance before any riveting or permanent bolting of floors is done.

As erection proceeds, inspector should match pieces against erection plans to see that proper piece is in correct position. Usually material is properly marked, but where there is any doubt, section of member should be checked.

The inspector should make sure that rivets or turned bolts are used where called for on erection plans or specifications. If there is any question

as to what connection is to be used, inspector should check with engineer's office.

Rivets should be checked for size and tightness. The alignment of holes should be checked before driving. Where they are not true, holes should be reamed and larger rivets driven. If rivet is tight and has full head, it should be passed.

In no case should the following be allowed:

Burning of holes with torch.
Gouging of holes with drift pins.
Tightening of rivet by calking of head.

Rivets should be tested with small hammer. Strike rivet head with several good blows of hammer to see if it can be "floated" or moved up and down. Defective rivets should be marked with chalk. When a loose rivet is removed, it may loosen adjoining rivets. In small groups, it may be necessary to remove all the rivets in group. However, as a rivet shrinks in cooling, a slight vibration is not cause for condemning a rivet. Sufficient temporary bolts should be used to hold pieces tight together while riveting.

Bolted connections should be reasonably tight but should not be turned up so as to strip thread. Where washer, lock washer, lock nuts, etc., are called for, they should be checked.

Beams on walls should be checked for proper wall bearing and anchorage.

Inspector should cooperate with the erector in safeguarding structure from accidents during erection. He should see that derrick base is secured from horizontal thrust of boom in any direction. Steel carrying derricks should be strong enough and have sufficient connections for erection stresses involved. The erectors should be warned against such dangerous practices as lifting too heavy a load for the strength of counter ties of derrick, booming out too far and splicing of boom. Guying and bracing of steel in process of erection against wind pressure are important. Shrinkage of a wet rope should be allowed for.

Painting should be done according to specifications. Where shop paint has been removed during shipment, repainting should be done before erection. Field paint should be of different color from shop paint. All steel should be free from rust and scale and should be dry. Painting should not be permitted in freezing weather.

Inspector should be familiar with design of building if possible. In any event, he should confer with the engineer to see whether there are any special connections which should be watched. If, in the opinion of inspector, any part of the structure does not appear structurally sound, he should notify engineer.

# TABLE 19. STRUCTURAL STEEL SECTIONS

## Amer. Std. Channel Sect.

| D | Wt | S | t | d | b | D | Wt | S | t | d | b | D | Wt | S | t | d | b | D | Wt | S | t | d | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 58 | 74.5 | .70 | 18 | 4¼ | | | | | | | 9 | 20 | 13.5 | .45 | 9 | 2⅝ | 6 | 13.0 | 5.8 | .44 | 6 | 2⅛ |
| 18 | 51.9 | 69.1 | .60 | 18 | 4⅛ | 12 | 30 | 26.9 | .51 | 12 | 3⅛ | [ | 15 | 11.3 | .28 | 9 | 2½ | [ | 10.5 | 5.0 | .31 | 6 | 2 |
| [ | 45.8 | 63.7 | .50 | 18 | 4 | [ | 25 | 23.9 | .39 | 12 | 3 | | 13.4 | 10.5 | .23 | 9 | 2⅜ | | 8.2 | 4.3 | .20 | 6 | 1⅞ |
| | 42.7 | 61.0 | .45 | 18 | 4 | | 20.7 | 21.4 | .28 | 12 | 3 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | 5 | 9.0 | 3.5 | .32 | 5 | 1⅞ |
| | 50 | 53.6 | .72 | 15 | 3¾ | | | | | | | 8 | 18.75 | 10.9 | .49 | 8 | 2½ | [ | 6.7 | 3.0 | .19 | 5 | 1¾ |
| 15 | 40 | 46.2 | .52 | 15 | 3½ | | | | | | | [ | 13.75 | 9.0 | .30 | 8 | 2⅜ | | | | | | |
| [ | 33.9 | 41.7 | .40 | 15 | 3⅜ | | 30 | 20.6 | .67 | 10 | 3 | | 11.5 | 8.1 | .22 | 8 | 2¼ | 4 | 7.25 | 2.3 | .32 | 4 | 1¾ |
| | 50 | 48.1 | .79 | 13 | 4⅜ | 10 | 25 | 18.1 | .53 | 10 | 2⅞ | | | | | | | [ | 5.4 | 1.9 | .18 | 4 | 1⅝ |
| | | | | | | [ | 20 | 15.7 | .38 | 10 | 2¾ | 7 | 14.75 | 7.7 | .42 | 7 | 2¼ | | | | | | |
| 13 | 40 | 41.7 | .56 | 13 | 4⅛ | | 15.3 | 13.4 | .24 | 10 | 2⅝ | [ | 12.25 | 6.9 | .31 | 7 | 2¼ | 3 | 6.0 | 1.4 | .36 | 3 | 1⅝ |
| [ | 35 | 38.6 | .45 | 13 | 4⅛ | | | | | | | | 9.8 | 6.0 | .21 | 7 | 2⅛ | [ | 5.0 | 1.2 | .26 | 3 | 1½ |
| | 31.8 | 36.5 | .38 | 13 | 4 | | | | | | | | | | | | | | 4.1 | 1.1 | .17 | 3 | 1⅜ |

## Amer. Std. Beam Sect.

| D | Wt | S | t | d | b | D | Wt | S | t | d | b | D | Wt | S | t | d | b | D | Wt | S | t | d | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 120 | 250.9 | .80 | 24 | 8 | 18 | 70 | 101.9 | .71 | 18 | 6¼ | 10 | 35 | 29.2 | .59 | 10 | 5 | 5 | 14.75 | 6.0 | .49 | 5 | 3¼ |
| 24 | 105.9 | 234.3 | .62 | 24 | 7⅞ | I | 54.7 | 88.4 | .46 | 18 | 6 | I | 25.4 | 24.4 | .31 | 10 | 4⅝ | I | 10.0 | 4.8 | .21 | 5 | 3 |
| I | 100 | 197.6 | .75 | 24 | 7¼ | | | | | | | | | | | | | | | | | | |
| | 90 | 185.8 | .62 | 24 | 7⅛ | | | | | | | 8 | 23.0 | 16.0 | .44 | 8 | 4⅛ | | | | | | |
| | 79.9 | 173.9 | .50 | 24 | 7 | 15 | 50 | 64.2 | .55 | 15 | 5⅝ | I | 18.4 | 14.2 | .27 | 8 | 4 | | | | | | |
| | | | | | | I | 42.9 | 58.9 | .41 | 15 | 5½ | | | | | | | 4 | 9.5 | 3.3 | .33 | 4 | 2¾ |
| | | | | | | | | | | | | 7 | 20.0 | 12.0 | .45 | 7 | 3⅞ | I | 7.7 | 3.0 | .19 | 4 | 2⅝ |
| | 95 | 160.0 | .80 | 20 | 7¼ | | 50 | 50.3 | .69 | 12 | 5½ | I | 15.3 | 10.4 | .25 | 7 | 3⅝ | | | | | | |
| 20 | 85 | 150.2 | .65 | 20 | 7 | 12 | 40.8 | 44.8 | .46 | 12 | 5¼ | | | | | | | | | | | | |
| I | 75 | 126.3 | .64 | 20 | 6⅜ | I | 35 | 37.8 | .43 | 12 | 5⅛ | 6 | 17.25 | 8.7 | .47 | 6 | 3⅝ | 3 | 7.5 | 1.9 | .35 | 3 | 2½ |
| | 65.4 | 116.9 | .50 | 20 | 6¼ | | 31.8 | 36.0 | .35 | 12 | 5 | I | 12.5 | 7.3 | .23 | 6 | 3⅜ | I | 5.7 | 1.7 | .17 | 3 | 2⅜ |

NOMENCLATURE

$D$ = nominal depth in inches.
Wt = weight per foot in pounds.
$S$ = Section modulus.
$t$ = web thickness in inches.
$d$ = actual depth in inches.
$b$ = flange width in inches.
I = American Standard Section.

# TABLE 19. STRUCTURAL STEEL SECTIONS (Continued)

## Bethlehem and Carnegie Structural Sections

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 36 WF | 300 | 1105.1 | .94 | 36¾ | 16⅝ |
| | 280 | 1031.2 | .88 | 36½ | 16⅝ |
| | 260 | 951.1 | .84 | 36¼ | 16½ |
| | 245 | 892.5 | .80 | 36 | 16½ |
| | 230 | 835.5 | .76 | 35⅞ | 16½ |
| | 194 | 663.6 | .77 | 36½ | 12⅛ |
| | 182 | 621.2 | .72 | 36⅜ | 12⅛ |
| | 170 | 579.1 | .68 | 36⅛ | 12 |
| | 160 | 541.0 | .65 | 36 | 12 |
| | 150 | 502.9 | .62 | 35⅞ | 12 |
| 33 WF | 240 | 811.1 | .83 | 33½ | 15⅞ |
| | 220 | 740.6 | .77 | 33¼ | 15¾ |
| | 200 | 669.6 | .71 | 33 | 15¾ |
| | 152 | 486.4 | .63 | 33½ | 11⅝ |
| | 141 | 446.8 | .60 | 33¼ | 11½ |
| | 130 | 404.8 | .58 | 33⅛ | 11½ |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 24 WF | 160 | 413.5 | .66 | 24¾ | 14⅛ |
| | 145 | 372.5 | .61 | 24½ | 14 |
| | 130 | 330.7 | .56 | 24¼ | 14 |
| | 120 | 299.1 | .56 | 24¼ | 12⅛ |
| | 110 | 274.4 | .51 | 24⅛ | 12 |
| | 100 | 248.9 | .47 | 24 | 12 |
| | 94 | 220.9 | .52 | 24¼ | 9 |
| | 84 | 196.3 | .47 | 24⅛ | 9 |
| | 76 | 175.4 | .44 | 23⅞ | 9 |
| 21 WF | 142 | 317.2 | .66 | 21½ | 13⅛ |
| | 127 | 284.1 | .59 | 21¼ | 13 |
| | 112 | 249.6 | .53 | 21 | 13 |
| | 96 | 197.6 | .57 | 21⅛ | 9 |
| | 82 | 168.0 | .50 | 20⅞ | 9 |
| | 73 | 150.7 | .45 | 21¼ | 8¼ |
| | 68 | 139.9 | .43 | 21⅛ | 8¼ |
| | 62 | 126.4 | .40 | 21 | 8¼ |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 14 WF | 426 | 707.4 | 1.87 | 18¾ | 16¾ |
| | 398 | 656.9 | 1.77 | 18¼ | 16⅝ |
| | 370 | 608.1 | 1.65 | 18 | 16½ |
| | 342 | 559.4 | 1.54 | 17½ | 16⅜ |
| | 314 | 511.9 | 1.41 | 17¼ | 16¼ |
| | 287 | 465.5 | 1.31 | 16¾ | 16⅛ |
| | 264 | 427.4 | 1.20 | 16½ | 16 |
| 14 WF | 320 | 492.8 | 1.89 | 16¾ | 16¾ |
| | 246 | 397.4 | 1.12 | 16¼ | 16 |
| | 237 | 382.2 | 1.09 | 16⅛ | 15⅞ |
| | 228 | 367.8 | 1.04 | 16 | 15⅞ |
| | 219 | 352.6 | 1.00 | 15⅞ | 15⅞ |
| | 211 | 339.2 | .98 | 15¾ | 15¾ |
| | 202 | 324.9 | .93 | 15⅝ | 15¾ |
| | 193 | 310.0 | .89 | 15½ | 15¾ |
| | 184 | 295.8 | .84 | 15⅜ | 15⅝ |
| | 176 | 281.9 | .82 | 15¼ | 15⅝ |
| | 167 | 267.3 | .78 | 15⅛ | 15⅝ |
| | 158 | 253.4 | .73 | 15 | 15½ |
| | 150 | 240.2 | .69 | 14⅞ | 15½ |
| | 142 | 226.7 | .68 | 14¾ | 15½ |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 12 WF | 190 | 263.2 | 1.06 | 14⅜ | 12⅝ |
| | 161 | 222.2 | .90 | 13⅞ | 12½ |
| | 133 | 182.5 | .75 | 13⅜ | 12⅜ |
| | 120 | 163.4 | .71 | 13⅛ | 12⅜ |
| | 106 | 144.5 | .62 | 12⅞ | 12¼ |
| | 99 | 134.7 | .58 | 12¾ | 12¼ |
| | 92 | 125.0 | .54 | 12⅝ | 12⅛ |
| | 85 | 115.7 | .49 | 12½ | 12⅛ |
| | 79 | 107.1 | .47 | 12⅜ | 12⅛ |
| | 72 | 97.5 | .43 | 12¼ | 12 |
| | 65 | 88.0 | .39 | 12⅛ | 12 |
| 12 WF | 58 | 78.1 | .36 | 12¼ | 10 |
| | 53 | 70.7 | .34 | 12 | 10 |
| | 50 | 64.7 | .37 | 12¼ | 8⅛ |
| | 45 | 58.2 | .34 | 12 | 8 |
| | 40 | 51.9 | .29 | 12 | 8 |
| | 36 | 45.9 | .30 | 12¼ | 6⅝ |
| | 31 | 39.4 | .27 | 12⅛ | 6½ |
| | 27 | 34.1 | .24 | 12 | 6½ |
| | 22 | 25.3 | .26 | 12¼ | 4 |
| | 19 | 21.4 | .24 | 12⅛ | 4 |
| | 16.5 | 17.5 | .23 | 12 | 4 |
| | 14 | 14.8 | .20 | 11⅞ | 4 |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 8 WF | 67 | 60.4 | .57 | 9 | 8¼ |
| | 58 | 52.0 | .51 | 8¾ | 8¼ |
| | 48 | 43.2 | .40 | 8½ | 8⅛ |
| | 40 | 35.5 | .36 | 8¼ | 8⅛ |
| | 35 | 31.1 | .31 | 8⅛ | 8 |
| | 31 | 27.4 | .29 | 8 | 8 |
| | 28 | 24.3 | .29 | 8 | 6½ |
| | 24 | 20.8 | .24 | 7⅞ | 6½ |
| | 20 | 17.0 | .25 | 8⅛ | 5¼ |
| | 17 | 14.1 | .23 | 8 | 5¼ |
| | 15 | 11.8 | .24 | 8⅛ | 4 |
| | 13 | 9.9 | .23 | 8 | 4 |
| | 10 | 7.8 | .17 | 7⅞ | 4 |
| 8 C | 34.3 | 28.9 | .37 | 8 | 8 |
| | 25 | 16.8 | .32 | 6⅜ | 6 |
| | 20 | 13.4 | .26 | 6¼ | 6 |
| | 15.5 | 10.1 | .24 | 6 | 6 |
| 6 WF | 16 | 10.1 | .26 | 6¼ | 4 |
| | 12 | 7.24 | .23 | 6 | 4 |
| | 8.5 | 5.07 | .17 | 5⅞ | 4 |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 30 WF | 210 | 649.9 | .77 | 30⅜ | 15⅛ |
| | 190 | 586.1 | .71 | 30⅛ | 15 |
| | 172 | 528.2 | .65 | 29⅞ | 15 |
| | 132 | 379.7 | .61 | 30¼ | 10½ |
| | 124 | 354.6 | .58 | 30⅛ | 10½ |
| | 116 | 327.9 | .56 | 30 | 10½ |
| | 108 | 299.2 | .54 | 29⅞ | 10½ |
| 27 WF | 177 | 492.8 | .72 | 27¼ | 14⅛ |
| | 160 | 444.5 | .66 | 27⅛ | 14 |
| | 145 | 402.9 | .60 | 26⅞ | 14 |
| | 114 | 299.2 | .57 | 27¼ | 10⅛ |
| | 102 | 266.3 | .52 | 27⅛ | 10 |
| | 94 | 242.8 | .49 | 26⅞ | 10 |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 18 WF | 114 | 220.1 | .59 | 18½ | 11⅞ |
| | 105 | 202.2 | .55 | 18⅜ | 11¾ |
| | 96 | 184.4 | .51 | 18⅛ | 11¾ |
| | 85 | 156.1 | .53 | 18⅜ | 8⅞ |
| | 77 | 141.7 | .47 | 18⅛ | 8¾ |
| | 70 | 128.2 | .44 | 18 | 8¾ |
| | 64 | 117.0 | .40 | 17⅞ | 8¾ |
| | 60 | 107.8 | .42 | 18¼ | 7½ |
| | 55 | 98.2 | .39 | 18⅛ | 7½ |
| | 50 | 89.0 | .36 | 18 | 7½ |
| 16 WF | 96 | 166.1 | .53 | 16⅜ | 11½ |
| | 88 | 151.3 | .50 | 16⅛ | 11½ |
| | 78 | 127.8 | .53 | 16⅜ | 8⅝ |
| | 71 | 115.9 | .49 | 16⅛ | 8½ |
| | 64 | 104.2 | .44 | 16 | 8½ |
| | 58 | 94.1 | .41 | 15⅞ | 8½ |
| | 50 | 80.7 | .38 | 16¼ | 7⅛ |
| | 45 | 72.4 | .35 | 16⅛ | 7 |
| | 40 | 64.4 | .31 | 16 | 7 |
| | 36 | 56.3 | .30 | 15⅞ | 7 |

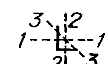
| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 14 WF | 136 | 216.0 | .66 | 14¾ | 14¾ |
| | 127 | 202.0 | .61 | 14⅝ | 14¾ |
| | 119 | 189.4 | .57 | 14½ | 14⅝ |
| | 111 | 176.3 | .54 | 14⅜ | 14⅝ |
| | 103 | 163.6 | .49 | 14¼ | 14⅝ |
| | 95 | 150.6 | .46 | 14⅛ | 14½ |
| | 87 | 138.1 | .42 | 14 | 14½ |
| 14 WF | 84 | 130.9 | .45 | 14⅛ | 12 |
| | 78 | 121.1 | .43 | 14 | 12 |
| | 74 | 112.3 | .45 | 14¼ | 10⅛ |
| | 68 | 103.0 | .42 | 14 | 10 |
| | 61 | 92.2 | .38 | 13⅞ | 10 |
| | 53 | 77.8 | .37 | 14 | 8 |
| | 48 | 70.2 | .34 | 13¾ | 8 |
| | 43 | 62.7 | .31 | 13⅝ | 8 |
| | 38 | 54.6 | .31 | 14⅛ | 6¾ |
| | 34 | 48.5 | .29 | 14 | 6¾ |
| | 30 | 41.8 | .27 | 13⅞ | 6¾ |

| D | Wt | S | t | d | b |
|---|---|---|---|---|---|
| 10 WF | 112 | 126.3 | .75 | 11⅜ | 10⅜ |
| | 100 | 112.4 | .68 | 11⅛ | 10⅜ |
| | 89 | 99.7 | .61 | 10⅞ | 10¼ |
| | 77 | 86.1 | .53 | 10⅝ | 10¼ |
| | 72 | 80.1 | .51 | 10½ | 10⅛ |
| | 66 | 73.7 | .46 | 10⅜ | 10⅛ |
| | 60 | 67.1 | .41 | 10¼ | 10⅛ |
| | 54 | 60.4 | .37 | 10⅛ | 10 |
| | 49 | 54.6 | .34 | 10 | 10 |
| 10 WF | 45 | 49.1 | .35 | 10⅛ | 8 |
| | 39 | 42.2 | .32 | 10 | 8 |
| | 33 | 35.0 | .29 | 9¾ | 8 |
| | 29 | 30.8 | .29 | 10¼ | 5¾ |
| | 25 | 26.4 | .25 | 10⅛ | 5¾ |
| | 21 | 21.5 | .24 | 9⅞ | 5¾ |
| | 19 | 18.8 | .25 | 10¼ | 4 |
| | 17 | 16.2 | .24 | 10⅛ | 4 |
| | 15 | 13.8 | .23 | 10 | 4 |
| | 11.5 | 10.5 | .18 | 9⅞ | 4 |
| 6 C | 25 | 15.7 | .31 | 6 | 6 |
| | 20 | 12.9 | .25 | 6 | 6 |
| 5 WF | 18.9 | 9.5 | .31 | 5 | 5 |
| | 18.5 | 9.9 | .26 | 5⅛ | 5 |
| | 16 | 8.5 | .24 | 5 | 5 |
| 4 C | 13 | 5.2 | .25 | 4 | 4 |
| 4 B | 13 | 5.45 | .28 | 4⅛ | 4 |
| | 10 | 4.16 | .22 | 4 | 4 |

### Nomenclature

$D$ = nominal depth in inches.
Wt = weight per foot in pounds.
$S$ = section modulus.
$t$ = web thickness in inches.
$d$ = actual depth in inches.
$b$ = flange width in inches.
$B$ = Bethlehem Steel Co. Section.
$C$ = U. S. Steel Corp. Section.

### Properties of Angles




| Size | S 1–1 | Area | r 1–1 | r 3–3 | Size | S 1–1 | S 2–2 | Area | r 1–1 | r 2–2 | r 3–3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2½ x 2½ x ¼ | .39 | 1.19 | .77 | .49 | 2½ x 2 x ¼ | .38 | .25 | 1.06 | .78 | .59 | .42 |
| 3 x 3 x ¼ | .58 | 1.44 | .93 | .59 | 3 x 2½ x ¼ | .56 | .40 | 1.31 | .95 | .75 | .53 |
| 3 x 3 x 5⁄16 | .71 | 1.78 | .92 | .59 | 3½ x 3 x ¼ | .78 | .59 | 1.56 | 1.11 | .91 | .63 |
| 3½ x 3½ x ¼ | .79 | 1.69 | 1.09 | .69 | 4 x 3 x ¼ | 1.0 | .60 | 1.69 | 1.28 | .90 | .65 |
| 3½ x 3½ x 5⁄16 | .98 | 2.09 | 1.08 | .69 | 4 x 3 x 5⁄16 | 1.2 | .73 | 2.09 | 1.27 | .89 | .65 |
| 4 x 4 x ¼ | 1.1 | 1.94 | 1.25 | .80 | 5 x 3½ x 5⁄16 | 1.9 | 1.0 | 2.56 | 1.61 | 1.03 | .77 |
| 4 x 4 x 5⁄16 | 1.3 | 2.40 | 1.24 | .79 | 5 x 3½ x ⅜ | 2.3 | 1.2 | 3.05 | 1.60 | 1.02 | .76 |
| 5 x 5 x ⅜ | 2.4 | 3.61 | 1.56 | .99 | 5 x 3½ x 7⁄16 | 2 6 | 1.4 | 3.53 | 1.59 | 1.01 | .76 |
| 6 x 6 x ⅜ | 3.5 | 4.36 | 1.88 | 1.19 | 6 x 4 x ⅜ | 3.3 | 1.6 | 3.61 | 1.93 | 1.17 | .88 |
| 6 x 6 x 7⁄16 | 4.1 | 5.06 | 1.87 | 1.19 | 6 x 4 x 7⁄16 | 3.8 | 1.9 | 4.18 | 1.92 | 1.16 | .87 |
| 6 x 6 x ½ | 4.6 | 5.75 | 1.86 | 1.18 | 6 x 4 x ½ | 4.3 | 2.1 | 4.75 | 1.91 | 1.15 | .87 |

## TABLE 20. WIRE AND SHEET METAL GAGES IN DECIMALS OF AN INCH *

| Name of Gage | United States Standard Gage † | | American Steel & Wire Co.,‡ and John A. Roebling Sons Co. | American or Brown & Sharpe Wire Gage | New Birmingham Standard Sheet and Hoop Gage | British Imperial or English Legal Standard Wire Gage | Birmingham or Stubs Iron Wire Gage | Name of Gage |
|---|---|---|---|---|---|---|---|---|
| Principal Use | Uncoated steel sheets and light plates | | Steel wire except music wire | Non-ferrous sheets and wire | Iron and steel sheets and hoops | Wire | Strips, bands, hoops, and wire | Principal Use |
| Gage No. | Weight, lb. per sq. ft. | Approx. Thickness, inches | Thickness, inches | | | | | Gage No. |
| 7/0's | 20.00 | 0.4902 | 0.4900 | | 0.6666 | 0.500 | | 7/0's |
| 6/0's | 18.75 | .4596 | .4615 | 0.5800 | .625 | .464 | | 6/0's |
| 5/0's | 17.50 | .4289 | .4305 | .5165 | .5883 | .432 | 0.500 | 5/0's |
| 4/0's | 16.25 | .3983 | .3938 | .4600 | .5416 | .400 | .454 | 4/0's |
| 3/0's | 15.00 | .3676 | .3625 | .4096 | .500 | .372 | .425 | 3/0's |
| 2/0's | 13.75 | .3370 | .3310 | .3648 | .4452 | .348 | .380 | 2/0's |
| 0 | 12.50 | .3064 | .3065 | .3249 | .3964 | .324 | .340 | 0 |
| 1 | 11.25 | .2757 | .2830 | .2893 | .3532 | .300 | .300 | 1 |
| 2 | 10.625 | .2604 | .2625 | .2576 | .3147 | .276 | .284 | 2 |
| 3 | 10.00 | .2451 | .2437 | .2294 | .2804 | .252 | .259 | 3 |
| 4 | 9.375 | .2298 | .2253 | .2043 | .250 | .232 | .238 | 4 |
| 5 | 8.75 | .2145 | .2070 | .1819 | .2225 | .212 | .220 | 5 |
| 6 | 8.125 | .1991 | .1920 | .1620 | .1981 | .192 | .203 | 6 |
| 7 | 7.50 | .1838 | .1770 | .1443 | .1764 | .176 | .180 | 7 |
| 8 | 6.875 | .1685 | .1620 | .1285 | .1570 | .160 | .165 | 8 |
| 9 | 6.25 | .1532 | .1483 | .1144 | .1398 | .144 | .148 | 9 |
| 10 | 5.625 | .1379 | .1350 | .1019 | .1250 | .128 | .134 | 10 |
| 11 | 5.00 | .1225 | .1205 | .0907 | .1113 | .116 | .120 | 11 |
| 12 | 4.375 | .1072 | .1055 | .0808 | .0991 | .104 | .109 | 12 |
| 13 | 3.75 | .0919 | .0915 | .0720 | .0882 | .092 | .095 | 13 |
| 14 | 3.125 | .0766 | .0800 | .0641 | .0785 | .080 | .083 | 14 |
| 15 | 2.8125 | .0689 | .0720 | .0571 | .0699 | .072 | .072 | 15 |
| 16 | 2.50 | .0613 | .0625 | .0508 | .0625 | .064 | .065 | 16 |
| 17 | 2.25 | .0551 | .0540 | .0453 | .0556 | .056 | .058 | 17 |
| 18 | 2.00 | .0490 | .0475 | .0403 | .0495 | .048 | .049 | 18 |
| 19 | 1.75 | .0429 | .0410 | .0359 | .0440 | .040 | .042 | 19 |
| 20 | 1.50 | .0368 | .0348 | .0320 | .0392 | .036 | .035 | 20 |

**TABLE 20. WIRE AND SHEET METAL GAGES IN DECIMALS OF AN INCH (Continued) ***

| Name of Gage | United States Standard Gage † | | American Steel & Wire Co.,‡ and John A. Roebling Sons Co. | American or Brown & Sharpe Wire Gage | New Birmingham Standard Sheet and Hoop Gage | British Imperial or English Legal Standard Wire Gage | Birmingham or Stubs Iron Wire Gage | Name of Gage |
|---|---|---|---|---|---|---|---|---|
| Principal Use | Uncoated steel sheets and light plates | | Steel wire except music wire | Non-ferrous sheets and wire | Iron and steel sheets and hoops | Wire | Strips, bands, hoops, and wire | Principal Use |
| Gage No. | Weight, lb. per sq. ft. | Approx. Thickness, inches | Thickness, inches | | | | | Gage No. |
| 21 | 1.375 | .0337 | .0318 | .0285 | .0349 | .032 | .032 | 21 |
| 22 | 1.25 | .0306 | .0286 | .0253 | .0313 | .028 | .028 | 22 |
| 23 | 1.125 | .0276 | .0258 | .0226 | .0278 | .024 | .025 | 23 |
| 24 | 1.00 | .0245 | .0230 | .0201 | .0248 | .022 | .022 | 24 |
| 25 | .875 | .0214 | .0204 | .0179 | .0220 | .020 | .020 | 25 |
| 26 | .75 | .0184 | .0181 | .0159 | .0196 | .018 | .018 | 26 |
| 27 | .6875 | .0169 | .0173 | .0142 | .0175 | .0164 | .016 | 27 |
| 28 | .625 | .0153 | .0162 | .0126 | .0156 | .0148 | .014 | 28 |
| 29 | .5625 | .0138 | .0150 | .0113 | .0139 | .0136 | .013 | 29 |
| 30 | .50 | .0123 | .0140 | .0100 | .0123 | .0124 | .012 | 30 |
| 31 | .4375 | .0107 | .0132 | .0089 | .0110 | .0116 | .010 | 31 |
| 32 | .4062 | .0100 | .0128 | .0080 | .0098 | .0108 | .009 | 32 |
| 33 | .375 | .0092 | .0118 | .0071 | .0087 | .0100 | .008 | 33 |
| 34 | .3438 | .0084 | .0104 | .0063 | .0077 | .0092 | .007 | 34 |
| 35 | .3125 | .0077 | .0095 | .0056 | .0069 | .0084 | .005 | 35 |
| 36 | .2812 | .0069 | .0090 | .0050 | .0061 | .0076 | .004 | 36 |
| 37 | .2656 | .0065 | .0085 | .0045 | .0054 | .0068 | | 37 |
| 38 | .25 | .0061 | .0080 | .0040 | .0048 | .0060 | | 38 |
| 39 | .2344 | .0057 | .0075 | .0035 | .0043 | .0052 | | 39 |
| 40 | .2188 | .0054 | .0070 | .0031 | .0039 | .0048 | | 40 |

* *From American Institute of Steel Construction.*

† U.S. Standard Gage is officially a weight gage (in ounces per square foot) based on wrought iron at 480 lb. per cu. ft. The values tabulated above give the thickness of steel (at 489.6 lb. per cu. ft.) that will approximate the respective weights. The other gages are officially thickness gages.

Plates, over 6 in. to 48 in. wide, 1/4 in. and thicker; over 48 in. wide, 3/16 in. and thicker.

Sheets, 24 in. to 48 in. wide, under 1/4 in. thick; over 48 in. wide, under 3/16 in. thick.

Strip, 23 15/16 in. and narrower, under 1/4 in. thick.

‡ Formerly Washburn & Moen.

______________________
Engineer

## REPORT ON STRUCTURAL STEEL—RIVETED OR BOLTED FIELD INSPECTION

Report No. ________

Job ______________________________ Date __________

Reported to ______________________________ Temp. __________

| | Erected during this period | Erected to date | Plumbed | Riveted | Accepted |
|---|---|---|---|---|---|
| Columns | | | | | |
| Beams | | | | | |
| | | | | | |
| | | | | | |

Worked from approved erection plans and specifications ____________

The fact that shop inspection has been made has been verified ________

All steel accepted has been inspected and approved as follows with special attention to the following:

All members have been checked against plans for piece mark and location

______________________________

Column bases, leveled and grouted ______________________

Columns plumbed ______________________

Riveting where called for on plans ____________ Quality __________

Bolting quality ______________________

Painting ______________________

Every column splice has been inspected for true bearing ____________

Ends of beams on seat connections are within $1\frac{1}{16}$ in. maximum of face of supporting members______________________

Remarks (rejections, corrections, etc.) ______________________

______________________________

______________________
Inspector

______________________
Engineer

# REPORT ON STRUCTURAL STEEL—RIVETED OR BOLTED

## Shop Inspection, Part I

---

Report No. ________
Job ______________________________ Date ____________
Reported to ____________________ Where Inspected ____________

---

Approved drawings used for inspection, shop drawings, erection plan, joint details ______________________

Steel inspected for:
Surface defects, folds, twists, straightness ______________
All sections called for on plans ______________
Connections agree with details and for correct location ______________
All members requiring bearing ends have full square-milled bearing ______

---

Stiffeners are full in contact at both ends for plate girders and at the ends shown in contact for seats and rolled sections ______________

All skewed connecting angles and plates have been bent hot ______________

---

Rivets are tight and of correct diameter ______________

The ends of beams bearing on seat connections will be not more than $1\frac{1}{16}$ in. maximum from the face of column or supporting member ______________

Not more than 2 of the rivets are punched more than $\frac{1}{16}$ in. off for any connections and not more than $\frac{1}{4}$ in. in any case ______________

Material has been properly cleaned before painting ______________
Painting is according to specifications or drawings ______________
Sample of shop coat paint has been taken for analysis ______________
Inspector has marked every member after accepting same ______________
No member has been shipped without inspector's mark except ______________
Inspector has marked on plans and column schedule all members accepted

---

Members have been assembled to insure proper alignment and fit, and freedom from twists, bends, and open joints between the component parts ______

---

Inspector will be able to state in final report that every member has been covered ______________

Special requests have been attended to ______________
Remarks (rejections, corrections, attention to warning notes, etc.) ______

______________________________________________

______________________________________________

______________________
Inspector

________________
Engineer

# REPORT ON STRUCTURAL STEEL

## Shop Inspection, Part II
*(For both riveted and welded steel)*

Report No. __________

Job ________________________________ Date __________

Reported to ____________________ Where Inspected __________

| Material | Required | Being Fabricated | Finished | Shipments | | | Weights |
|---|---|---|---|---|---|---|---|
| | | | | Date | R.R. | Car No. | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |
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| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Remarks ________________________________________

Shipped this report ______________________________

Previous _______________________________________

Total to date ___________________________________

________________
Inspector

Mill ____________________
Client ____________________
Project ____________________

____________________
Engineer

STEEL MILL REPORT *

Date ____________________
Report ____________________
Sheet ________ of ________
Specification ____________________

Requirements

| Quantity | Description of Material | Weight | Heat Number | Yield Pt. Per Sq. In. | Ultimate per Sq. In. | % Elongation In. | % Reduction Area | Bend | Chemical Tests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Car. | Man. | Phos. | Sul. | |
| | | | | | | | | | | | | | |

Total this report ____________________
Previous ____________________
Total to date ____________________

The above tests do / do not fulfil A.S.T.M. Spec. ______, ______ Grade

____________________
Inspector

* *Adapted from Haller Engineering Associates, Inc.*

# WELDING

## COMMON WELDING PROCESSES

Figures 22 and 23 indicate common welding processes and the action of the shielded arc electrode. In the electric arc welding process a metal electrode is melted and fuses with contiguous metal surfaces to be joined. The welding heat is obtained from the electric arc formed between the electrode and the parts to be welded. The temperature of the arc is approximately 10,000° F.

In the metal arc process if the direction of flow of current is through ground lead, into work, into electrode, into work lead, and back to machine, the circuit is known as electrode negative (straight polarity). With the electrode positive (reverse polarity) the direction of the flow of current is reversed. In alternating-current welding the direct-current generator is replaced by a transformer. Direct current with electrode positive (reverse polarity) is used for structural work except where deep penetration is required. The type of electrodes affects the polarity, as electrodes can be used only as shown in Table 21, p. 68, on account of the material of the covering.

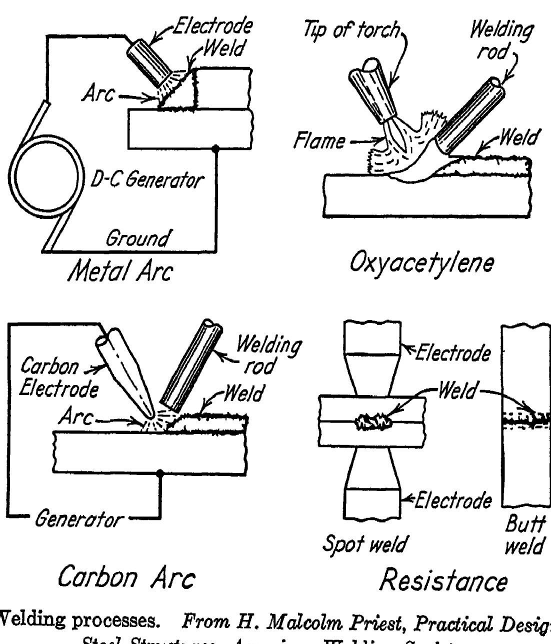



FIG. 22. Welding processes. *From H. Malcolm Priest, Practical Design of Welded Steel Structures, American Welding Society.*

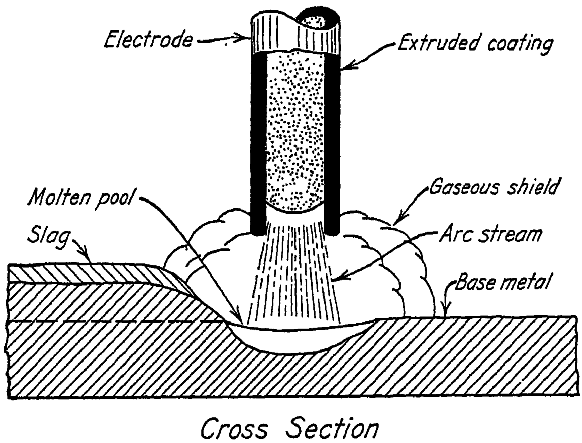



FIG. 23. Shielded arc electrode. *From H. Malcolm Priest, Practical Design of Welded Steel Structures, American Welding Society.*

## WELDERS' QUALIFICATION TEST USING FILLET WELDS

Take two bars 5 in. by ½ in. by 4 in., and weld as indicated in Fig. 24 in the desired position, that is, flat, horizontal, vertical, or overhead. Turn plates over and break with a blow by a sledge hammer. The weld should break cleanly along the center line, showing a clean cross section of weld material. Visual inspection of the weld and its fracture readily reveals any improper fusion between the weld and base metal or any lack of soundness.

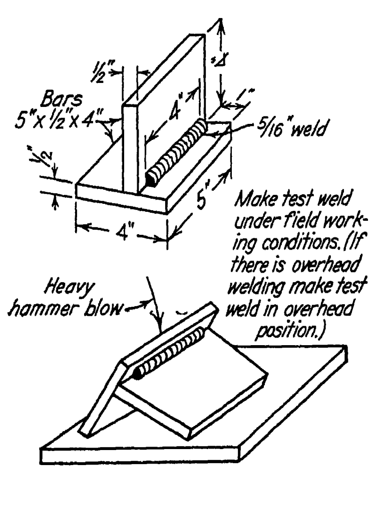



FIG. 24. Test for weld soundness.

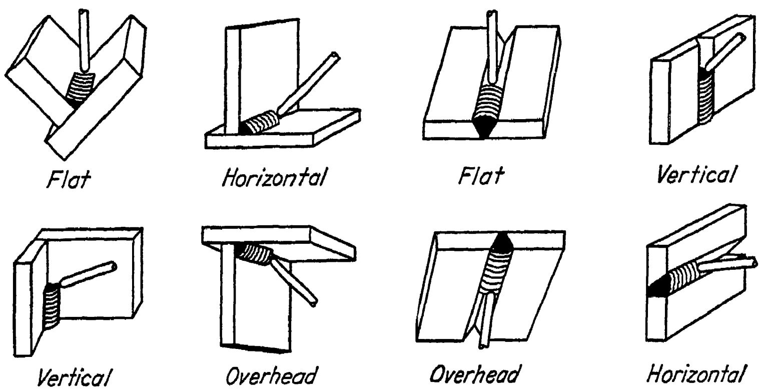



Fig. 25. Welding positions. *From H. Malcolm Priest, Practical Design of Welded Steel Structures, American Welding Society.*

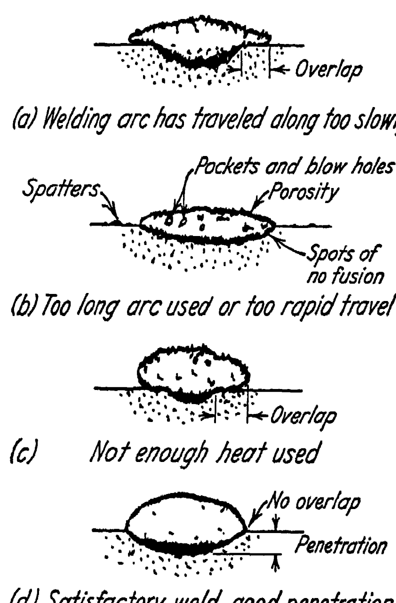



Fig. 26. Weld characteristics under certain conditions. *From Gilbert D. Fish, Arc-Welded Steel Frame Structures, McGraw-Hill Book Company.*

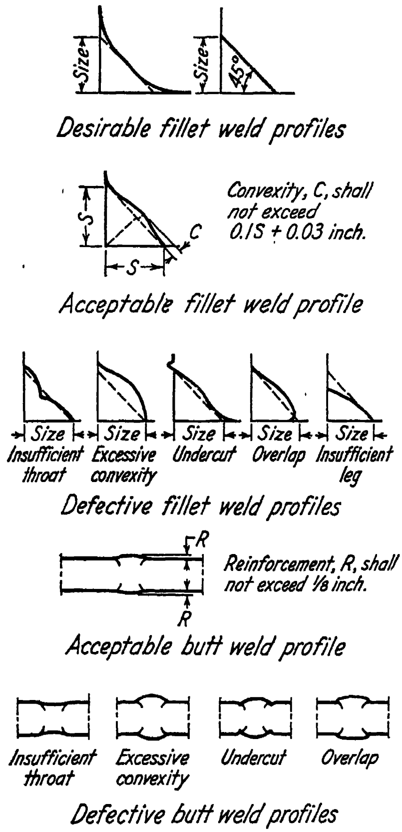



FIG. 27. Illustrations of acceptable and defective welds as contained in A.W.S. Code. *From Specifications for Design, Fabrication and Erection of Structural Steel for Buildings by Arc and Gas Welding, 1942, American Institute of Steel Construction.*

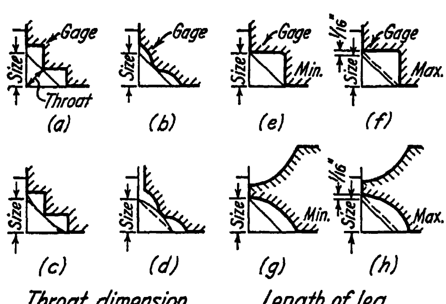



FIG. 28. Fillet weld gages. *From H. Malcolm Priest, Practical Design of Welded Steel Structures, American Welding Society.*

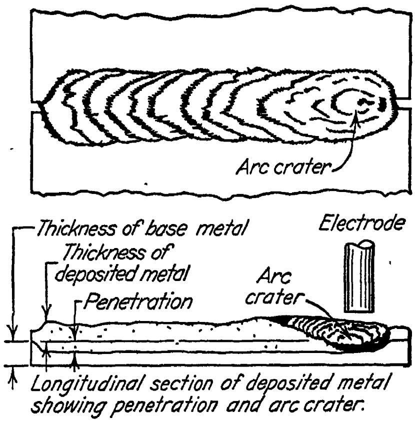



FIG. 29. Weld penetration and arc crater. *From Gilbert D. Fish, Arc-Welded Steel Frame Structures, McGraw-Hill Book Company.*

## TABLE 21. ELECTRODES AND THEIR USES (A.W.S. SPEC.)

| Electrode Classification Number | Capable of Producing Satisfactory Welds in Positions Shown | General Description | Remarks |
|---|---|---|---|
| E6010 | *F, V, OH, H* * | Heavy covering, useful with direct current, electrode positive (reverse polarity) only. | These electrodes, called slow electrodes, are used in both shop and field. They produce a slower weld than E6020 and E6030. The weld pool can be controlled in all positions. E6010 is used for root pass of flat welds. |
| E6011 | *F, V, OH, H* | Heavy covering, useful with alternating current only. | |
| E6012 | *F, V, OH, H* | Heavy covering, usually used with electrode negative (straight polarity), direct or alternating current. | |
| E6013 | *F, V, OH, H* | Heavy covering, usually used with alternating current. | |

| Electrode Classification Number | Capable of Producing Satisfactory Welds in Positions Shown | General Descripion | Remarks |
|---|---|---|---|
| E6020 | *F*, *H* fillets | Heavy covering, usually used with electrode negative (straight polarity) or alternating current for fillets; and electrode positive (reverse polarity) or alternating current for flat welding. | These electrodes, called fast electrodes, are usually used in shop and only in positions indicated as weld pool has to be controlled by fast welding. |
| E6030 | *F* | Heavy covering, usually used with electrode positive (reverse polarity) on direct current, or with alternating current. | |

* *F* = flat; *V* = vertical; *OH* = overhead; *H* = horizontal.

### TABLE 22. MAXIMUM SIZE OF ELECTRODES

| Type | Position: Flat | Horizontal | Vertical | Overhead |
|---|---|---|---|---|
| Fillet | 1/4 in. | 5/16 in. | 3/16 in. | 3/16 in. |
| Butt | 1/4 in. | 3/16 in. | 3/16 in. | 3/16 in. |

*Note:* Maximum size of fillet weld in one pass is 5/16 in., except that vertical welds can be 1/2 in.

Electrodes for a single pass fillet weld and for root pass of a multilayer weld shall be of proper size to insure thorough fusion and penetration with freedom from slag incursions, but shall not exceed 5/32 in. diameter for butt welds, vertical and overhead fillet welds.

Read off electrode container recommended current. Check vs. current being used.

To find current being used, time rate of electrode burn-off, find current from chart on following page.

Example. Given 5/32 electrode and burn-off rate of 12 in. in 70 seconds. Enter chart at 70 seconds, proceed across to intersection with 5/32 in. curve, drop vertical to ampere scale, read 150 amperes.

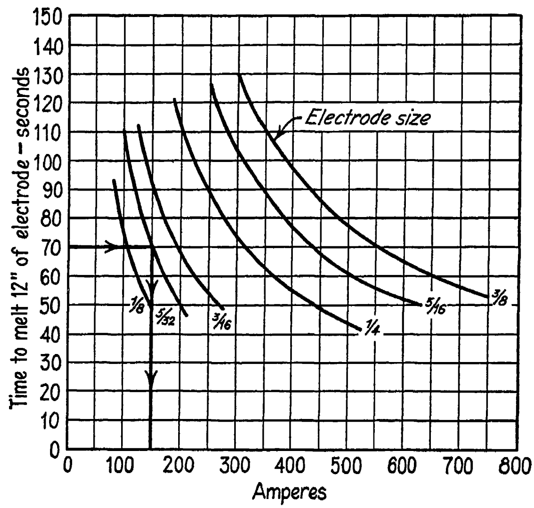



Chart to determine welding current by rate of electrode melt-off. *From Procedure Handbook of Arc Welding—Design and Practice, The Lincoln Electric Company.*

## CHECK LIST FOR INSPECTORS

### WELDING

*See also "Check List for Inspectors, Structural Steel," p. 53.*

**Extra Equipment for Structural Welded Job**

Welding gage.
Chipping hammer.
Wire brush.
Protective shield.

**Procedure in Inspection**

Qualifications of welder. If there is any question as to his qualifications, he should be required to make test pieces for inspector.

Conformity of electrodes to specifications or correct usage. See p. 68. For current actually used, see above chart.

Condition and capacity of welding equipment.

Quality of welds for overlap, color, porosity, slag inclusions, undercutting, uniformity, and workmanlike appearance.

Fitting up of members for tightness. In fillet welds when the gap exceeds 1/16 in., size of weld should be increased.

Sequence of welding in order to minimize residual stresses.

Condition of any tack welds which are to be fused with final welds. If any of these are not satisfactory, they should be removed.

Cleanliness of work, as good welds cannot be made on dirt, rust, or slag. In a multiple pass weld, slag must be chipped and wire brushed to shiny surface before next pass is made.

Weather conditions, as welding should not be done in temperature less than 0° F., or when surfaces are wet from condensation, rain, snow, or ice. Welder should be properly protected from wind. At temperatures between 0° F. and 32° F., surfaces must be heated. Material 1½ in. thick or over should be 70° F. minimum.

Conformity to approved plans for the following details:

Cross-sectional size, length, location, and omission. They should not be increased arbitrarily as longer welds sometimes introduce more restraint than calculated.

Operator at work at frequent intervals. If welding is not being properly done, he should be corrected. An experienced welder knows when he is making a good weld. He also knows whether equipment is working properly and will tell you.

## IDENTIFICATION OF IRON AND STEEL

| | White Cast Iron * | Gray Cast Iron | Malleable † Iron |
|---|---|---|---|
| Fracture | Very fine silvery white silky crystalline formation | Dark gray | Dark gray |
| Unfinished surface | Evidence of sand mold; dull gray | Evidence of sand mold; very dull gray | Evidence of sand mold; dull gray |
| Newly machined | Rarely machined | Fairly smooth; light gray | Smooth surface; light gray |

| | Wrought Iron | Low-Carbon Steel and Cast Steel | High-Carbon Steel |
|---|---|---|---|
| Fracture | Bright gray | Bright gray | Very light gray |
| Unfinished surface | Light gray· smooth | Dary gray; forging marks may be noticeable; cast—evidences of mold | Dark gray; rolling or forging lines may be noticeable |
| Newly machined | Very smooth surface; light gray | Very smooth; bright gray | Very smooth; bright gray |

* Very seldom used commercially.
† Malleable iron should always be bronze-welded.

______________________
Engineer

## REPORT ON STRUCTURAL STEEL—WELDED

### Field Inspection

Project ______________________ Date ______________
Welding permit No. ______________________ Report No. ______________
Welding contractor ______________________
Description of work ______________________

| | Erected during this Period | Erected to Date | Plumbed | Welded | Accepted |
|---|---|---|---|---|---|
| Columns | | | | | |
| Beams | | | | | |
| | | | | | |
| | | | | | |

Shop welded or riveted ______________________
Weather and temperature ______________________
Checked against approved typical details and erection plans ______________

Machines ______________________
Electrodes * ____________ Sizes ______________ Polarity ______________
Weld sizes __________ No. of layers or beads __________ Symbol __________
Positions employed: horizontal __________ flat __________ vertical __________
overhead ______________________
All welders' qualifications checked ______________ Authority ______________
Has every welder marked joint with index number? ______________
Has inspector kept complete record of welding? ______________
Has every weld been checked for size? ______________ Length? ______________
Location? ____________ Quality? ____________ Workmanship? ____________
Number of individual welds made: ____________ Accepted: ____________
Rewelded: ______________________
Reasons for rejections and rewelding, method of correction of defective welds, and name and index numbers of welders making such defective welds:

______________________________________________

______________________________________________

______________________________________________

* See p. 68.

Inspector has marked on plans all joints accepted including column splices using separate prints where plans cover two or more tiers ________________

---

Before welding was the steel properly cleaned, and free from corrosion, water, oil, scale, dirt, paint, etc.? ________________

Were proper methods employed when setting up the work to insure tight fit without displacement of component parts after welding, together with full penetration of the weld metal to the root of the joints? ________________

---

Was inspector in full attendance at all times while welds or fusion was being made in the passing of metal from the electrode to the base metal? ____

---

Was each completed weld carefully examined for defects and irregularities such as: undercutting, overlaps, lack of fusion at edges, lack of penetration, place cracks adjacent to or behind weld, water cracks and cracks in weld metal, slag inclusions? ________________

Remarks ________________

---

Joints welded and accepted ________________

Inspector has marked every weld group after accepting them. ________________

---

________________

Inspector

____________________
Engineer

## REPORT ON STRUCTURAL STEEL—WELDED

Shop Inspection, Part I

(*See p. 62 for Part II.*)

---

Report No. ____________
Job ________________________ Date __________
Reported to ______________ Where inspected __________

---

Approved drawings used for inspection, shop drawings, erection plan, joint details __________
Steel inspected for surface defects, fold, twists, straightness __________
All sections are as called for on plans __________
Connections agree with details and for correct locations __________
All members requiring bearing ends have full square-milled bearing __________

---

Stiffeners are full in contact at both ends for plate girders and at the ends shown in contact for seats and rolled sections __________
All skewed connecting angles and plates have been bent hot __________

---

The ends of beams bearing on seat connections will be not more than $1\frac{1}{16}$ in. maximum from the face of column or supporting member __________

---

Material has been properly cleaned before painting __________
Painting is according to specifications or drawings __________
Sample of shop coat paint taken for analysis __________
Inspector has marked every member after accepting same __________
No member has been shipped without inspector's mark except __________

---

Inspector has marked on plans and column schedule all members accepted

---

Inspector will be able to state in final report that every member has been covered __________
Every weld inspected for size __________ length __________ location __________ and quality __________
Every welder has marked every weld group for identification __________
All welders' qualifications checked __________ Authority __________
Number of welders __________ Names __________

---

Make and capacity of machines __________
Kind of current __________
Make, grade, style No., and size of electrodes __________

---

Special requests have been attended to __________
Remarks (rejections, corrections, etc.) __________

---

____________________
Inspector

**Reports When under Construction**

| | |
|---|---|
| Structural steel | see pp. 60 to 63. |
| Concrete | see pp. 43 to 48. |
| Piles | see p. 88. |
| Timber | see p. 96. |
| Other items | |

**Field Data Required for Rating Existing Bridges if Plans Not Available**

Sizes of all members.

All span and panel point dimensions.

Sketches of all joints including dimensions and sizes of bolts, rivets, pins, connection angles, washers, etc.

Data for dead-load computations such as material and thickness of floor construction.

Live loads from using railroad or proper highway department.

## INSPECTION OF EXISTING BRIDGES *

**Waterway.** First show the area of the structure in square feet in the space provided.

Conditions in the streambed should be noted as to (1) adequacy of channel afforded by the existing structure; (2) probability of scour that may endanger the footings; and (3) presence of obstructions, such as drift logs, stumps, or old piers, that may be diverting the current so as to cause undermining of the footings. Also note any undergrowth or obstructions that can be removed to increase the adequacy of the waterway or to lessen the fire hazard of timber structures. Lastly, note whether stream-bank protection is necessary to keep the channel properly confined and thus to avoid endangering the bridge foundations or the end fills. Also note if there are any indications of unusual corrosiveness at the site.

**Piers and Abutments.** The type and material used should be listed.

**Timber Piles.** Piles supporting timber bridges should be inspected carefully at the ground line, where decay first sets in. A ¾-in. hexagonal steel bar about 4 ft. long, with one end sharpened to a long tapering point and the other end provided with a chisel face, is a very useful tool in such examinations. It can be jabbed into a pile to disclose deterioration not apparent on the surface and to determine the extent of sap rot. Piles in which the diameter of sound material has been reduced to 6 in. or less should be marked with yellow keel for replacement.

* *From Toncan Culvert Manuf. Assoc.*

**Steel Tubular Piers.** Steel tubular piers should be carefully examined for corrosion in rivets or bolt heads connecting the cylindrical sections. (The filling material in such steel cylinders is usually inferior and without strength in itself.) Also note whether there has been appreciable movement of the tubes due to impact of heavy loads on the structure; if so, additional footings or bracing may be needed. Note whether the steel tubes are out of plumb and if so whether this is due to undermining, to lack of proper bracing, or to inadequate support below. Examine base of tubes for exposed piling caused by scour.

**Concrete Substructures.** The pier shafts should be examined for damage from drift or ice. Examine exposed footings for rock pockets due to improper placement of concrete. Note extent of any undermining. Look for cracks, and note whether they are caused by unequal settlement, contraction, or fill pressure. Check abutments and adequacy of wing walls. Recommend placement of riprap and rock slope protection where necessary.

## Concrete Structures

**Culverts.** Examine barrel and wing walls of culverts to find any harmful cracks due to settlement that should be grouted to prevent deterioration of the reinforcing steel. Also examine floor of barrel to note any upheaval which may cause failure of side walls due to excessive fill pressure; especially note this in culverts under high fills.

**Beam-and-Slab Spans.** Note condition of railing for damage by collision; sight alignment of railing for indication of settlement of the structure. On heavily traveled roads, the handrail should be kept clean in order to provide proper visibility for night driving and, if conditions warrant, should be painted with a cement wash coat. Examine beams for cracks that may be due to clogged expansion joints, settlement, or fill pressure at either end of bridge. Note any surface checking in deck, railing, curbs, or sidewalks that may allow water to seep in and cause disintegration by freezing action.

## Steel Structures

On steel trusses note first the general alignment of the span to see whether the end posts and top chords are straight and in line. Any buckling indicates that the structure has been overloaded. Especially note this for light construction. Kinks in any one member may have been caused by damage in shipment, in erection, or by collision; the inspector should satisfy himself that any such kinks are not due to overstress.

For all pin-connected trusses, note whether eyebars in the same member are taking equal tension. Overloading or lack of proper camber adjustment may cause one eyebar to take all the stress, leaving the others loose on the pin. Especially note this for the diagonal and hip vertical mem-

bers. Observe the structure under heavy loading, and note whether there is any excessive deflection or bowing in or out of the diagonal eyebar members which would indicate lack of proper counterbracing. Note condition of end shoes and rollers to see whether proper expansion is being provided for and whether the rollers are free to move.

## Timber Structures

**Timber Trusses.** In inspecting a timber truss, first see if it has any noticeable sag. If sag is present note whether it is due to failure of splices, improper adjustment of vertical rods, or crushing of diagonal members. Examine all splices for splitting or cracking of the shear tables. Sound the rods with a hammer to note whether each is carrying the same amount of tension, and examine condition of caps and ends of diagonal members for signs of crushing. If the structure is very old, it will be advisable to use a ⅜-in. auger bit to test out the center of the top and bottom chord members for heart rot at all panel points and splices; the floor beams at contact with bottom chords should also be bored. Decay will be found first at contact points and where rods go through timber members.

Other points to check on covered trusses will be the condition of the roof and housing. Be sure to examine truss bearings over the pier caps and the condition of caps over pier piling for crushing, and bore with auger bit where there is any doubt as to their soundness. Note whether all bolts through splices, packing blocks, and cross bracing are tight and in good order. The substructure of timber trestles should be examined as directed under "Piers and Abutments." Caps should be examined for any crushing over the posts or piling. Decay will always be found first at bearing contacts, and a testing bar or auger bit should be used on all doubtful timbers. A thorough boring test must be made on all timbers that have been in place more than 6 years.

Note condition of bulkheads at each end of the bridge for decay, height, and proper retention of approach fill. Check sway and longitudinal bracing to note whether any members are broken or decayed and whether additional bracing is required. In examining the superstructure, first go under the bridge, examine each span, and note (1) whether stringers are crushing, cracking, or splitting, (2) whether they have full bearing over the caps, and (3) whether bridging between stringers is in place. Note condition of under side of decking, and see whether all bolts are properly tightened or have become loose due to shrinkage of timbers.

Second, examine deck and handrail from roadway. Especially on high bridges, sound handrail posts with testing bar at contact with felloe guard, stringers, and railing to see that members are not badly decayed. Handrail should be kept painted for protection against decay and to provide visibility for night traffic; all decayed members must be replaced. Timber handrails require repainting about every 3 years.

## FIELD DATA FOR NEW SMALL BRIDGES

The following bridge inspection report on p. 80 is devoted to data that should be gathered in the field for the replacement of an existing small bridge with a new structure. All data requested in the heading is self-explanatory; however, it should be emphasized that, if the existing structure is noticeably too small or too large, then the area to be drained, expressed as drainage area in acres, should be as accurate as possible. Likewise, the correct value for $c$ should be shown for use in the Talbot formula.

Fill in the data requested for the respective type; however, if a decision as to proper selection has not been made, it is advisable to list the data for both pipe and arches since very little extra time will be required to develop the additional information.

It is important that the profile of the stream bed and road and location sketch be as accurate as possible. Be sure to indicate on the location sketch any suggested desired change in location for the new structure.

EXISTING BRIDGE INSPECTION REPORT *

Bridge No. ________ Route No. ________ ________ Miles from ________ Toward ________
Bridge over ________ Type ________ Date built ________
Overall length ________ Width between rails ________ Vertical clearance ________
Load capacity ________ Approaches ________ Date inspected ________
H-10, H-15, or H-20
H 20-S16 or H 15-S12

OBSERVATIONS

| Waterway Area ____ sq. ft. | | Piers and Abutments Type ________ | | Concrete Structures and Floors | | Steel Construction Type ________ | | Timber Spans and Floors | |
|---|---|---|---|---|---|---|---|---|---|
| Adequacy | ___ | Undermining | ___ | Cracking | ___ | Condition of paint | ___ | Condition of paint | ___ |
| Scour | ___ | Settlement | ___ | Scaling | ___ | Corrosion | ___ | Decay | ___ |
| Obstructions | ___ | Cracking | ___ | Scour | ___ | Joints | ___ | Wear (floors) | ___ |
| Undergrowth | ___ | Disintegration | ___ | Settlement | ___ | Loose rivets | ___ | Structural defects† | ___ |
| Channel shifting | ___ | Decay (lumber) | ___ | Disintegration | ___ | Camber | ___ | Crushing at joints | ___ |
| Revetments | ___ | Corrosion (steel) | ___ | Waterproofing | ___ | End shoes | ___ | Splices | ___ |
| Other features | ___ | Other defects | ___ | Other defects | ___ | Other defects | ___ | Camber | ___ |
| | ___ | Piling foundations? | ___ | | ___ | Wear | ___ | Other defects | ___ |

Make above observations for each part of structure, and note with (✓) mark to indicate "OK" or "None." For items needing explanation mark with circle with a number inserted to refer to corresponding remark listed below. Amplify remarks with sketches on second sheet when necessary.

REMARKS

(Use second sheet when space below is not sufficient; also, list causes of all defects such as cracking and scaling of concrete whenever possible.)

________

________

________

________

RECOMMENDATIONS

(Furnish data on p. 80 when total replacement is recommended)

| Item | Estimated Cost | |
|---|---|---|
| | Maintenance | Improvements |
| | | |
| | | |
| | | |
| | | |
| | | |

*Note.* List under maintenance and "Recommendations" all necessary channel clearing, revetments, bank protection, channel changes, stream-bed pavements, riprap work, underpinning or other foundation protection' shoulder and slope protection, repairs to concrete work, painting, waterproofing, preservative treatments, repairs to roadway surfaces, repairs and renewals to timber and piling, and all other maintenance and repair work of whatever nature.

Inspector

* *From Toncan Culvert Manuf. Assoc.*

† Under "Structural defects" note any tendency to warp, split, crack, etc.

# FIELD DATA FOR NEW STRUCTURE *

Location ____________ Width of roadway between outside of rails
Same—New
or shoulders ____________
Drainage area ________ Acres Talbot formula factor $c$ = ________
Distance between stream bed and roadway ____________
Slope of embankment ________ Type recommended ________
Pipe—Arch

---

## Additional Data for Pipe Structure

Waterway area required ________ sq. ft. Live load ________
Cover over pipe ________ No. of pipes ________ Diameter ________
Slope or skew ____________ Center line length ________
Headwalls or riprap ________ Type of material in stream bed ____
____________ Slope of stream ____________ %

---

## Additional Data for Arch Structure

Waterway area required ________ sq. ft. Live load ________
Cover over arch ________ No. of arches ________ Span ________
Rise ____________ Slope or skew ____________
Center-line length ________ Head walls or riprap ________
Bearing power of soil ________ Type of material in stream bed ____
Recommended material for abutments, piers, and walls ________
Depth of abutments and piers below stream bed ________
Slope of stream ____________ %

Profile of stream and road

Note. Indicate normal and flood level of stream.

Location sketch

Show angle of skew of structure with centerline of roadway.

____________
Inspector

* *From Toncan Culvert Manuf. Assoc.*

# PAINTING

## CHECK LIST FOR INSPECTORS

## TREATMENT OF SURFACES FOR PAINTING

### General Conditions

All surfaces to be painted shall be thoroughly dry.

No exterior painting to be done in rainy, damp, or frosty weather.

Permit no interior painting until surfaces have become thoroughly dry. (By artificial heating if necessary.)

Allow no painting on metal surfaces to be welded. If such surfaces have been painted, paint is to be removed.

All surfaces must be of material in compliance with specifications. Surfaces must be checked for shop coat where called for in specifications.

### Surface Preparation

**Metal Surfaces.** Remove dirt and mud by brushing and/or washing.

Remove grease and oil with benzine, naphtha, or turpentine.

Rust and scale to be removed with wire brush, steel scraper, or sand blasting.

Mill scale to be removed by burning.

Old paint to be removed by burning, scraping or paint remover.

Before painting over prime coat, check and reprime where necessary.

Before priming new galvanized metal wash with copper sulfate solution to remove grease and chemicals.

Before hot asphaltic applications, heat metal.

Where phosphoric acid treatment is specified, immerse material in caustic soda solution at 200° F. to remove grease and oils; rinse in hot water; immerse in 5% sulfuric acid pickle, then rinse in hot water.

**Wood Surfaces.** Remove dirt and dust with brush and rag.

Stop out all knots and sap streaks with shellac.

Putty nail holes, cracks, and other depressions after primer coat has thoroughly dried. Tint putty to match finish.

Old paint to be removed by sanding, wire brushing, scraping, or burning.

Floors to be sanded or scraped.

Open-grained woods to be varnished to be given first an application of wood paste filler thinned with turpentine.

**Masonry Surfaces.** Dust, dirt, and excess material to be removed with stiff bristle or wire brush.

Remove salts from brickwork with zinc sulfate water solution, and brush off surface when dry.

All masonry surfaces to be allowed thorough period for curing.

Porous block to be primed with casein paste or resin sealer.

Cement floors to be prepared by acid etching with muriatic acid to

improve adhesion; acid to be washed off and floor dried before painting.

Stucco and concrete to be cleaned with stiff fiber brush; traces of oil to be removed with abrasive stone or, if general, by light sand blasting. Sealer to be added to the paint.

Smooth dense concrete surfaces to be roughened by light sand blasting, muriatic acid etching, or rubbing with abrasive stone to improve adhesion.

Where cement paints are used on exterior concrete the surface to be dampened before application.

**Plaster Surfaces.** Allow 30 days for drying before painting.

Apply prime coat of sealer to clean dry surface.

Check prime coat for fading caused by hot spots (incomplete mixing of hydrated lime) and suction spots (thin spots and inadequate troweling).

## FOUNDATIONS ON SOIL

*Method of conducting a load test, N. Y. City code.* *See also Fig. 30, p. 83.*

**Procedure.** Apply sufficient load uniformly on platform to produce a center load of four times the proposed "design load per square foot."

Center load equals load of platform times $\dfrac{b}{a+b}$.

Read settlement every 24 hours until no settlement occurs in 24 hours.

Add 50% more load and read settlement every 24 hours until no settlement occurs in 24 hours.

Settlement under proposed load should not show more than ¾ in., or increment of settlement under 50% overload should not exceed 60% of settlement under proposed load.

If the above limitations are not met, repeat test with reduced load.

**TABLE 23. PRESUMPTIVE BEARING CAPACITY OF SOILS**

| Material | Capacity in Tons per Sq. Ft. |
|---|---|
| Hard sound rock | 40 |
| Medium hard rock | 25 |
| Hard pan overlaying rock | 10 |
| Soft rock | 8 |
| Gravel | 6 |
| Coarse sand | 4 |
| Fine dry sand | 3 |
| Hard dry sand | 3 |
| Sand and clay, mixed or in layers | 2 |
| Firm clay | 2 |
| Fine and wet sand (confined) | 2 |
| Soft clay | 1 |

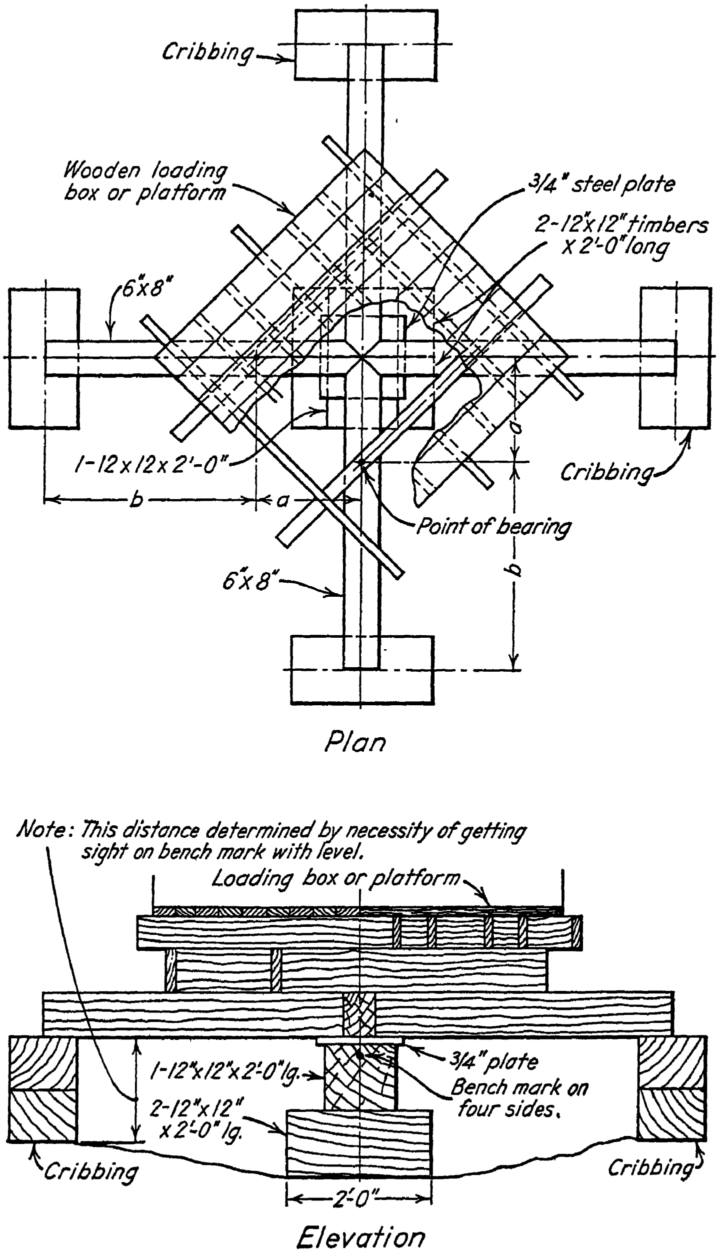



FIG. 30. Load test on soil.

## CHECK LIST FOR INSPECTORS

### FOUNDATIONS

Inspector should determine from plans the type of soil on which the foundation design is based and check against actual conditions.

Shallow pipe borings under each footing should be made if there is a question about the underlying soils.

If there is any question in regard to soil bearing capacity, inspector should notify engineer, who may according to his judgment revise size of footings or require footings to be carried deeper. Soil test may be required.

Keep footings clear of water when concrete is poured.

Soil to be original strata and below loam or vegetation.

Bottom elevation of footing to be at least the elevation called for on plan. If necessary, owing to soil condition, elevation may be lowered for suitable bearing.

Keep record of actual elevation of footings installed.

Check slope between footings when elevations differ from plans or when determined in field. This slope should not be more than 2 horizontal to 1 vertical for compact soils but should be fixed by the engineer.

Conditions which may require sheeting where impossible to keep minimum slope should be watched.

Possible undermining of existing foundations should be checked.

Footings should be of size shown on plans.

Concrete for footing. See "Instructions to Inspectors, Concrete."

# PILE DRIVING

## CHECK LIST FOR INSPECTORS AND DATA

### PILE DRIVING

**Procedure in Inspection**

Inspector should first determine from specifications the type of pile to be used, should familiarize himself with specifications, and should have approved drawings for his use in field.

Condition of pile or pile shells before driving.

Type of pile driver and size. Weight of striking part or ram and stroke.

Plumbing of pile or mandrel before driving.

Lateral tolerance of pile. Limit 3 in. from horizontal location.

Plumbness of pile. Limit 2% of pile length.

Pile shell just before concrete is poured with light for: buckling of shell, puncture of shell, water, ice, and snow.

Buckling of cast-in-place pile when another pile is being driven close. This can be detected by watching the concrete rise in shell. If concrete rises to any extent, pile should be replaced.

Heaving of pile when another pile is being driven close. This can be noticed by watching to see if the shell is being lifted out of ground. Condition may be relieved by driving an occasional open-end pipe pile.

Check concrete mix from specifications or drawings.

Protection of concrete against freezing.

Pile caps not laid on frozen ground.

Proper cutoff.

Injury to wood piles. Crushing or brooming of pile head or, in precast concrete piles, the cracking or disintegrating of concrete makes it impossible to drive piles properly as this dissipates the energy of the blow of hammer.

Possible telescoping or crushing of the middle of wooden piles as indicated by sudden loss of resistance.

Possible deflection of the foot of pile. This happens when pile hits a slanting surface of rock and then drives easier as result of the splitting or sliding of the bottom.

**Driving Control.** Check length of piles and blows per inch. Calculate required safe load on each pile as follows:

For drop hammer $P = \dfrac{2WH}{S + 1}$; for single-acting steam hammer, $P = \dfrac{2WH}{S + 0.1}$. The reason for the difference in the formulas is the extra speed of the steam hammer, which affects consolidation time between blows. Both are gravity-type hammers.

$P$ = safe load in pounds; $W$ = weight of striking part in pounds; $H$ = height of fall in feet or stroke in feet; $S$ = average penetration in inches under last 5 blows.

EXAMPLES. Given $W = 2000$ lb., $H = 15$ ft. 0 in., $S = 0.5$ in. Required $P$ using drop hammer

$$P = \frac{2 \times 2000 \times 15}{0.5 + 1} = 40{,}000 \text{ lb.}$$

Given $W = 5000$ lb., $H = 3$ ft. 0 in., $S = 0.4$ in. Required $P$ using single-acting steam hammer

$$P = \frac{2 \times 5000 \times 3}{0.4 + 0.1} = 60{,}000 \text{ lb.}$$

TABLE 24. BEARING POWER OF PILES IN THOUSANDS OF POUNDS DRIVEN WITH SINGLE-ACTING STEAM PILE HAMMERS AS PER FORMULA GIVEN IN TEXT

| Size of Hammer | Weight of Striking Part in Pounds | Length of Stroke in Feet | Penetration per Blow in Inches | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
| 2 | 3000 | 2.42 | 73 | 48 | 36 | 29 | 24 | 20 | 18 | 16 | 14 | 13 |
| 1 | 5000 | 3.00 | 150 | 100 | 75 | 60 | 50 | 43 | 37 | 33 | 30 | 27 |
| 0 | 7500 | 3.25 | 244 | 162 | 122 | 97 | 81 | 69 | 60 | 54 | 48 | 44 |
| OR | 9300 | 3.25 | 302 | 202 | 152 | 121 | 101 | 86 | 75 | 67 | 60 | 55 |

Safe load for piles driven by double-acting steam pile hammer though usually prohibited in specifications for friction piles may be checked by the following manufacturer's data:

**Bearing Power of Piles Driven with McKiernan-Terry Pile Hammers.** By the *Engineering News* formula, $P = \dfrac{2E}{S + 0.1}$, where $P$ = safe load in pounds; $E$ = energy or foot-pounds per blow (see Table 25); $S$ = average penetration in inches for last 5 blows. The assumed safety factor of this formula is 6. $E$ is computed from indicator diagram tests rather than from steam pressure.

TABLE 25. VALUES OF $E$ FOR McKIERNAN-TERRY PILE HAMMERS

| Size of Hammer | Ft-Lb. Blow at Given Strokes per Minute: Strokes per Min. | Ft-Lb. per Blow = $E$ | Size of Hammer | Ft-Lb. Blow at Given Strokes per Minute: Strokes per Min. | Ft-Lb. per Blow = $E$ |
|---|---|---|---|---|---|
| 7 | 225 | 4,150 | 9B2 | 100 | 3,700 |
| | 195 | 3,720 | | 105 | 4,200 |
| | 170 | 3,280 | | 110 | 4,750 |
| | | | | 115 | 5,350 |
| 9B3 | 145 | 8,750 | | 120 | 5,940 |
| | 140 | 8,100 | | 130 | 7,000 |
| | 135 | 7,500 | | 140 | 8,200 |
| | 130 | 6,800 | | | |
| | | | 10B2 | 100 | 10,700 |
| 10B3 | 105 | 13,100 | | 105 | 12,000 |
| | 100 | 12,000 | | 110 | 13,500 |
| | 95 | 10,900 | | 115 | 15,000 |
| | 90 | 9,550 | | | |
| | | | 11B2 | 100 | 15,600 |
| 11B3 | 95 | 19,150 | | 105 | 17,250 |
| | 90 | 18,300 | | 110 | 18,900 |
| | 85 | 17,500 | | 115 | 20,500 |
| | 80 | 16,700 | | 120 | 22,000 |

TABLE 26. BEARING POWER OF PILES IN THOUSANDS OF POUNDS USING MAXIMUM *E*

| Penetration per Blow in Inches | Size of Hammer | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7 | 9B3 | 10B3 | 11B3 | 9B2 | 10B2 | 11B2 |
| 0.1 | 41.5 | 87.5 | 131.0 | 191.5 | 82.0 | 150.0 | 220.8 |
| 0.2 | 27.6 | 58.3 | 87.3 | 127.6 | 54.6 | 100.0 | 147.2 |
| 0.3 | 20.7 | 43.7 | 65.5 | 95.7 | 41.0 | 75.0 | 110.4 |
| 0.4 | 16.6 | 35.0 | 52.4 | 76.6 | 32.8 | 60.0 | 88.3 |
| 0.5 | 13.8 | 29.1 | 43.6 | 63.8 | 27.3 | 50.0 | 73.6 |
| 0.6 | 11.8 | 25.0 | 37.4 | 54.7 | 23.4 | 42.9 | 63.2 |
| 0.7 | 10.3 | 21.8 | 32.7 | 47.8 | 20.5 | 37.5 | 55.3 |
| 0.8 | 9.2 | 19.4 | 29.1 | 42.5 | 18.2 | 33.3 | 49.1 |
| 0.9 | 8.3 | 17.5 | 26.2 | 38.3 | 16.4 | 30.0 | 44.1 |
| 1.0 | 7.5 | 15.9 | 23.8 | 34.8 | 14.9 | 27.3 | 40.1 |

Comments. The field engineer's checking criterion is the number of strokes per minute, rather than the steam pressure, and also penetration. If steam pressure falls off, the number of blows per minute cannot be delivered and the penetration falls off.

### Load Tests

Conduct as follows. A suitable balanced platform shall be built on top of pile which has been in place for at least 2 days. If it is a concrete pile, the concrete should be thoroughly hardened. Place initial load equal to the proposed pile load using heavy material such as pig iron. Increase this load 25% after 12 hours, and 25% after 24 hours, thus the total load is 150% of proposed load.

Allow final load to remain at least 48 hours. Take readings before and after placing of each load and 12 and 24 hours after placing final load.

The total net settlement deducting rebound after removing load should not be more than 0.01 in. per ton of total test load.

______________________
Engineer

# REPORT ON PILE DRIVING

## Field Inspection

Report No. __________

Job ______________________________________________ Date ______________

Reported to ____________________________________________________________

Hammer data ____________________________________________________________

| Footing No. | Pile No. | Penetration | No. Blows Last In. | No. Strokes per Min. | Bearing Capacity | Approved | Rejected | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

See field drawing No. ______ for field location of piles in this report ______

____________________________________________________________

______________________
Inspector

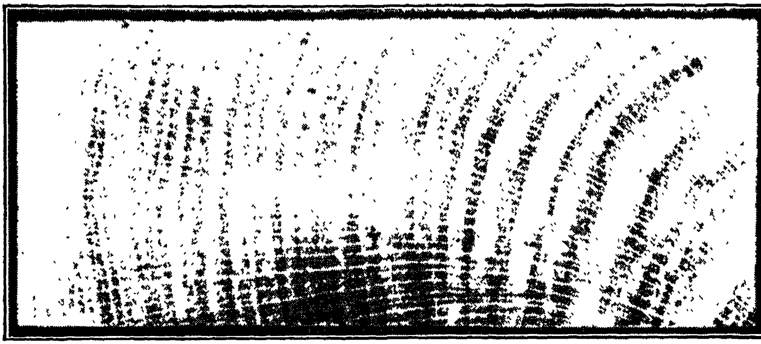
# TIMBER

## WOOD JOISTS—NET SECTION

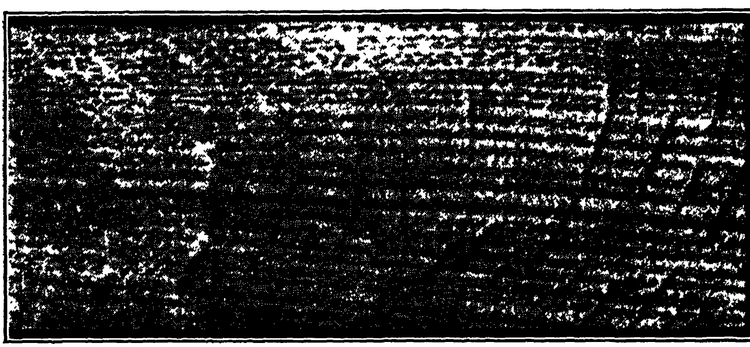
### TABLE 27. SECTION MODULI = $bd^2/6$

| Nom. Size | Actual Size | S | Nom. Size | Actual Size | S | Nom. Size | Actual Size | S | Nom. Size | Actual Size | S | Nom. Size | Actual Size | S | Nom. Size | Actual Size | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 × 4 | 1⅝ × 3⅝ | 3.56 | 3 × 4 | 2⅝ × 3⅝ | 5.75 | 4 × 4 | 3⅝ × 3⅝ | 7.94 | 6 × 6 | 5½ × 5½ | 27.7 | 8 × 8 | 7½ × 7½ | 70.3 | 10 × 10 | 9½ × 9½ | 143 |
| 2 × 6 | 1⅝ × 5⅝ | 8.57 | 3 × 6 | 2⅝ × 5⅝ | 13.8 | 4 × 6 | 3⅝ × 5⅝ | 19.1 | 6 × 8 | 5½ × 7½ | 51.6 | 8 × 10 | 7½ × 9½ | 113 | 10 × 12 | 9½ × 11½ | 209 |
| 2 × 8 | 1⅝ × 7½ | 15.3 | 3 × 8 | 2⅝ × 7½ | 24.6 | 4 × 8 | 3⅝ × 7½ | 34.0 | 6 × 10 | 5½ × 9½ | 82.7 | 8 × 12 | 7½ × 11½ | 165 | 10 × 14 | 9½ × 13½ | 289 |
| 2 × 10 | 1⅝ × 9½ | 24.4 | 3 × 10 | 2⅝ × 9½ | 39.5 | 4 × 10 | 3⅝ × 9½ | 54.5 | 6 × 12 | 5½ × 11½ | 121 | 8 × 14 | 7½ × 13½ | 228 | 10 × 16 | 9½ × 15½ | 380 |
| 2 × 12 | 1⅝ × 11½ | 35.8 | 3 × 12 | 2⅝ × 11½ | 57.9 | 4 × 12 | 3⅝ × 11½ | 79.9 | 6 × 14 | 5½ × 13½ | 167 | 8 × 16 | 7½ × 15½ | 300 | 10 × 18 | 9½ × 17½ | 485 |
| 2 × 14 | 1⅝ × 13½ | 49.4 | 3 × 14 | 2⅝ × 13½ | 79.7 | 4 × 14 | 3⅝ × 13½ | 110.0 | 6 × 16 | 5½ × 15½ | 220 | 8 × 18 | 7½ × 17½ | 383 | 10 × 20 | 9½ × 19½ | 602 |

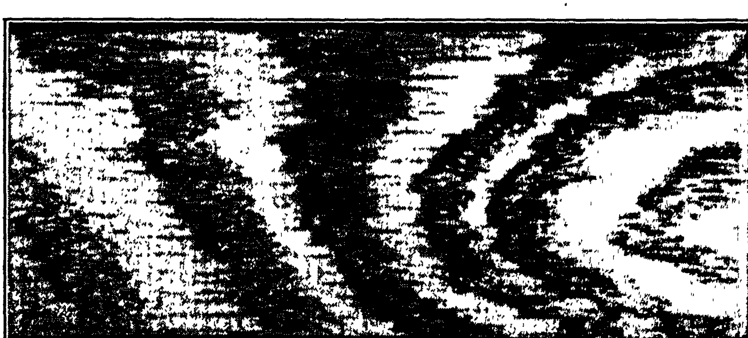
HARDWOODS—RED OAK



Transverse Section



Radial Section

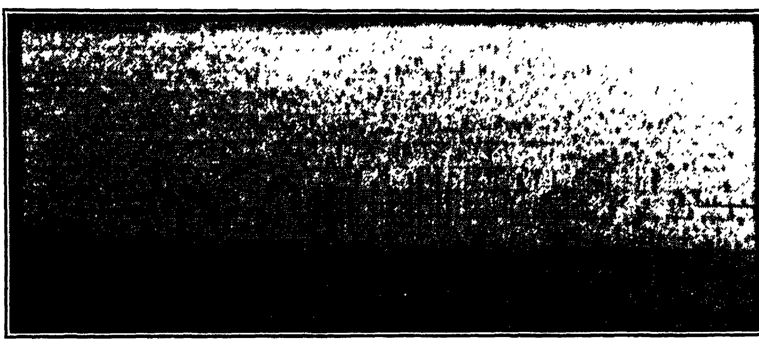


Tangential Section

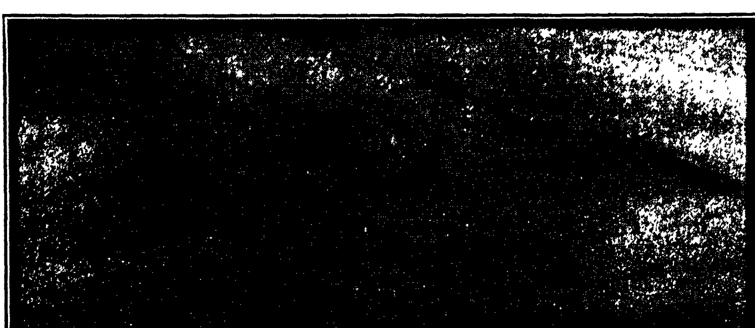
This illustration is representative of the oaks, which are all very strong and suitable for the manufacture of anything from piles to furniture. The wood is very heavy, the white oak is the most resistant to decay.

HARDWOODS—MAPLE

Transverse Section



Radial Section



Tangential Section

This illustration is representative of the maples, an excellent flooring and furniture material but not used very much as structural timber.

# CHECK LIST FOR INSPECTORS

## WOOD AND TIMBER CONSTRUCTION

### Inspectors' Equipment

Complete set of final structural plans, specifications, and approved shop details.

Copy of rules for stress grade of lumber.

6-foot rule.

Plumb bob.

Moisture meter.

### Procedure in Inspection

Grade of lumber checked. Material should be stamped with grade shown on plans or called for in specifications. The inspector should familiarize himself with rules for grading of lumber to be used so that he may check grading if from appearance it looks incorrect.

Selection of already graded lumber checked. Select beams so as to avoid slope of grain in lower third of beam steeper than 1:20. Slope of grain in tension member of truss not to be steeper than 1:20. Avoid knots in lower edge of beams. By utilizing elsewhere or inverting pieces which do not conform, these results should be attained without waste.

Imperfections that may have occurred after grading, such as broken fibers due to transportation, decay, and moisture content, which should not be more than 20%, to be checked. Moisture content may be checked with moisture meter if available; otherwise inspector will have to accept manufacturer's certificate of moisture at time of grading plus visual inspection.

Increased checks, loose knots, and warping due to unsatisfactory seasoning watched.

Sizes, lengths and spacing of all members checked.

Bearing and anchorage of beam, girder, or joists on masonry checked.

Plumbing, base, cap, and splice details of columns, especially checking bearing at ends, checked.

All special details shown on plans carefully followed.

Correct fabrication of built-up member such as laminated members and trusses. All members with bolts and ring connectors should be fabricated with standard tools and strictly according to instructions furnished by manufacturer of same.

Drilling and grooving of ring connector members. Any material that is incorrectly drilled or grooved must be rejected as it is impossible to correct it.

Tightness of bolts in bolted or connected work. These should be tightened up so hard that washer makes a slight impression in wood surface but not so as to tear fibers. After construction until seasoning, bolts should be given a periodical inspection for tightness and at the same time timber should be inspected for further checking. This particularly applies to ring connectors or keyed work as ring or key tends to rotate as bolts loosen.

Alignment, bearing, or connection of trusses after erection. They should be straight and in a vertical position, and bearing or connection in accordance with plans.

Gluing of glued laminated members. This is usually done in a shop with proper facilities. Inspector should check to see that specifications are followed exactly with special attention to the following: type and quality of glue, mixing of glue, amount of glue used, method of applying, moisture content of lumber, curing of members, and temperatures of manufacturing space. In field watch for tendency of laminations to separate.

Retouching of cut, preserved members, see specifications.

______________________
Engineer

# REPORT ON WOOD PRESERVATION *

## Plant Inspection

Report for ______________________

Material ______________________

Project ______________________

Producer ______________________

Contractor ______________ Specs. ______________

Treatment No. ______________ Report No. ______________ Date ______________

Charge No. ______________ Preservative ______________
Board feet ______________ Treatment specified ______________ Process ______________
Lineal feet ______________ Net retention ______________
Cubic feet ______________ Condition of ______________
Steam ______________ hours at ___ pounds maximum pressure ____ °F. maximum temperature
Vacuum ______________ hours at ___ inches maximum pressure ____ °F. minimum temperature
Air ______________ hours at ___ pounds maximum pressure ______________
Preservative ______________ hours at ___ pounds maximum pressure ____ °F. average temperature
Vacuum ______________ hours at ___ inches maximum mercury ____ °F. minimum temperature
Special operation ______________
Penetration ______________ Specific gravity or preservative ______________

| No. Pieces | Size | Length | Total Treated | Total to Date |
|---|---|---|---|---|

Remarks:

The above preservative and treatment fulfills the specification.

______________________
Inspector

* *Adapted from Haller Engineering Associates, Inc.*

# ROPES AND CABLE—STRENGTHS

## WEIGHT AND STRENGTH OF MANILA AND SISAL ROPE *

| Diameter, in. | Circumference, in. | Approx. Feet per Lb. | Ultimate Breaking Strength of Manila Rope (Min. Government Allowance), lb. | Safe Working Strains, lb. | Ultimate Breaking Strength of Sisal Rope (Min. Government Allowance), lb. | Safe Working Strains, lb. |
|---|---|---|---|---|---|---|
| 1/4 | 3/4 | 50.0 | 600 | 120 | 480 | 96 |
| 3/8 | 1 1/8 | 24.4 | 1,350 | 270 | 1,080 | 216 |
| 1/2 | 1 1/2 | 13.3 | 2,650 | 530 | 2,120 | 424 |
| 3/4 | 2 1/4 | 6.00 | 5,400 | 1,080 | 4,320 | 864 |
| 1 | 3 | 3.71 | 9,000 | 1,800 | 7,200 | 1,440 |
| 1 1/2 | 4 1/2 | 1.67 | 18,500 | 3,700 | 14,800 | 2,960 |
| 2 | 6 | .930 | 31,000 | 6,200 | 24,800 | 4,960 |

* *Adapted from American Manufacturing Company.*

## WIRE ROPE 6 x 19 STANDARD HOISTING—PLOW STEEL *

| Diameter, in. | 2 3/4 | 2 1/4 | 2 | 1 7/8 | 1 3/4 | 1 5/8 | 1 1/2 | 1 3/8 | 1 1/4 | 1 1/8 | 1 | 7/8 | 3/4 | 5/8 | 9/16 | 1/2 | 7/16 | 3/8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Breaking strength, tons of 2000 lb. | 254.0 | 174.0 | 139.0 | 123.0 | 108.0 | 93.4 | 80.0 | 67.5 | 56.2 | 45.7 | 36.4 | 28.0 | 20.7 | 14.5 | 11.8 | 9.35 | 7.19 | 5.31 |

* *From John A. Roebling's Sons Company.*

## VARIETIES OF KNOTS

A great number of knots have been devised, of which only a few are illustrated, but those selected are the most frequently used. See Fig. 31.

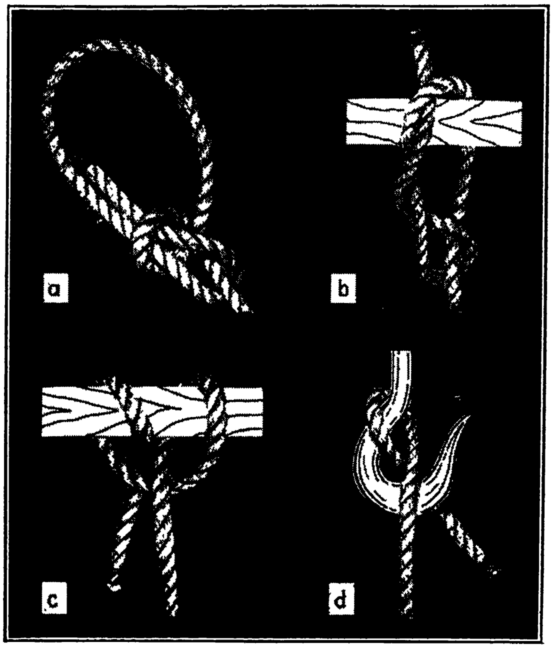



FIG. 31. *From American Manufacturing Company.*

*a.* Bowline. Makes a slip-proof loop. Popular because it is easy to untie.
*b.* Timber hitch. For securing a line to logs or planks. For lifting or dragging.
*c.* Clove hitch. For attaching rope to a fixed object, or small rope to a larger one.
*d.* Blackwall hitch. A temporary hook tie. More secure with two turns around hook.

# SOILS

## SURVEYING AND SAMPLING METHODS

### TABLE 28. EXPLORATION AND SAMPLING METHODS *

| Method | Material in Which Used | Penetration Method | Sampling Method | Type of Sample | Purpose or Value |
|---|---|---|---|---|---|
| Rod sounding or jet probing | All soils except hardpan or boulders | Driving 1 in. steel rod or ¾ in. jet pipe with hand pump | No sample | | To obtain depth of muck or soft strata. Location ledge or boulders. Otherwise valueless. |
| Wash borings | | Washing inside 2½ in. driven casing with chopping bit on end of 1 in. extra heavy pipe | Sample recovered from sediment in wash water | Disturbed-sedimentary, coarse grains only | Depth to ledge or boulders; otherwise valueless. Results deceptive and dangerous. |
| Dry sample boring | | | Open-end pipe or split spoon sampler driven into soil | Disturbed but not separated | Density data from penetration of spoon. Fairly reliable and inexpensive. |
| Special sampling devices | Cohesive soils | Driven casing or auger boring | By special sampling spoon or device | Undisturbed | To obtain samples for laboratory study |
| Auger boring | Cohesive soils. Cohesionless soils above ground water | Soil, wood or post hole; auger rotated by hand or machine and withdrawn | Sample recovered from soil brought up by auger | Disturbed but better than wash samples | To locate soil strata and ground water. Roads, airfields, canals, and railroads. Samples for visual inspection and soil profile. |
| Well or churn drilling | All soils including boulders, rock, and gravel | Churn drilling by power | Bailed sample of churned material or use of "clay socket" | "Clay socket" or "dry" | Occasionally used for foundations. "Bailed" samples worthless. |
| Rotary drilling | | Rotating bit | From circulating liquid | Fluid | Samples worthless |
| Core drill borings | Large boulders and solid rock | Diamond, shot, or saw-tooth cutters | Cores cut and recovered | Rock cores ⅞ in. and over in diameter | Best method to obtain type and condition of rock |
| Test pits and caissons | All soils; below ground water use pneumatic caisson or lower water table | Excavate by hand or power; pit over 6 ft. sheeted or lagged | Bulk sample by hand; undisturbed sample with spoon, tube, or special device | Disturbed or undisturbed | Most satisfactory method; should supplement others. To obtain undisturbed sample cohesionless soil. Soil can be inspected in natural condition. |
| Geophysical, seismic, electric resistance, electric potential | No samples. Continuous vibration or impulse from dynamite explosion. Device to register vibrations. Mostly patented methods. | | | | Primary exploration will indicate earth, loose rock, or solid rock. Interpretation uncertain. |

* *Adapted from "Low Dams" by Natural Resources Comm., based on Harvard Grad. Eng. School Pub. 208 by H. A. Mohr.*

## SPACING AND DEPTH OF BORINGS AND TEST PITS OR TEST HOLES

**Highways.*** At 100 ft. stations plus additional necessary at culverts, bridges, weak zones, wide cuts and fills, muck deposits, borrow pits, and sources of base material. Depth not less than 3 ft. below subgrade. Locate ground water table, seepage sources, and direction of flow.

**Airfields.†** At 100-ft. to 1000-ft. spacing on center line, edge of pavement and edge of shoulders. Depth not less than 4 to 6 ft. below subgrade in cut or ground surface in fill. Not less than twice diameter of tire contact area nor less than frost penetration. Locate ground water table and seepage data. Make field load-bearing tests at time of survey (from 5 to 10 usual for each airfield).

**Bridges, Dams, and Piers.‡** Borings spaced as needed to bedrock or well below foundation level. Make borings at least 20 ft. into solid rock. Make 1 or more borings at each pier 50 ft. minimum into solid rock. Use open-pit exploration on land and in shallow water. Make soil bearing tests and pile loading tests.

**Building Foundations, Towers, Chimneys, etc.‡** Borings spaced not over 50 ft. center to center. Depth 15 ft. to 20 ft. minimum below foundation level. Initial borings to depth = 2 × width loaded area.

Core borings into rock greater than minimum design depth of rock required. Supplement borings with test pits, load tests, and test piles.

### TABLE 29. SIZE OF SAMPLES

Visual inspection and record, 1 qt. mason jar.
California bearing ratio, 125 lb.
Soil stabilization, 125 lb.
Physical constants and mech. analysis, 5–15 lb.
Aggregates for construction (concrete), 35 lb.
Moisture-density (Proctor tests), 10–35 lb.
Undisturbed sample, 12″ to 2′ long x 3″ to 5″ diam.
Rock core, usually ⅞″ to 1½″ diam.

*Note.* Seal undisturbed samples in tube with paraffin so structure and moisture content are not disturbed. Place bulk (disturbed) samples in bag or container tight enough so fines will not be lost.

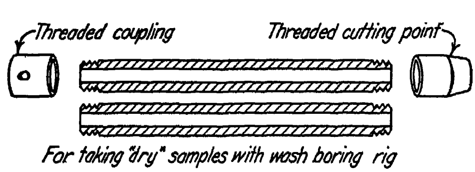



FIG. 32. Split spoon sampler.

* A.S.T.M. D-420, C.A.A. Specs.
† P.R.A., U.S.E.D., A.A.F., C.A.A.
‡ Man. Eng. Practice 8, A.S.C.E.

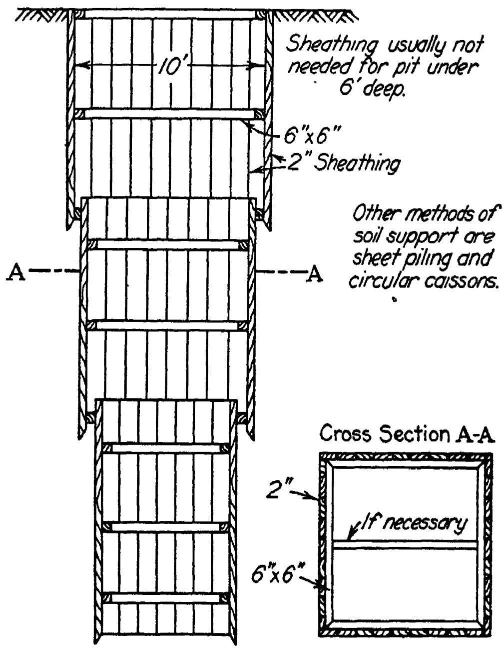



FIG. 33. Test pit (sheathed and braced). *Krynine, Soil Mechanics, McGraw-Hill Book Company.*

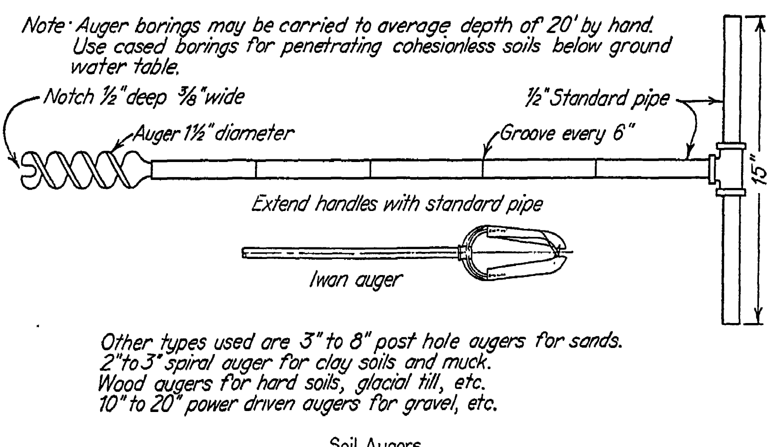



FIG. 34. Soil auger.

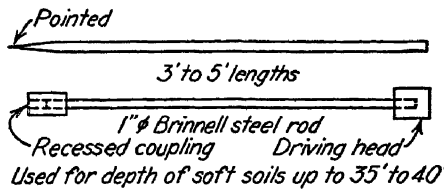



FIG. 35. Sounding rod.

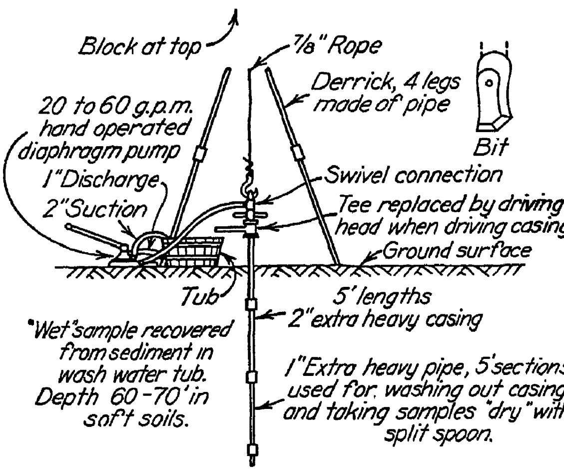



FIG. 36. Wash boring rig. *After Mohr.*

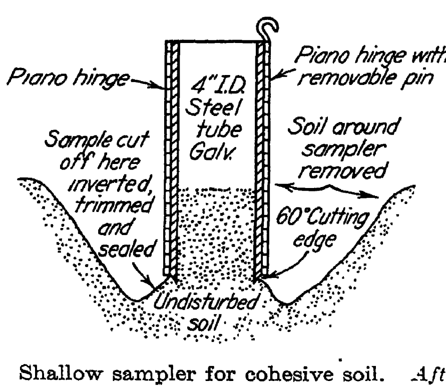



FIG. 37. Shallow sampler for cohesive soil. *After Taylor.*

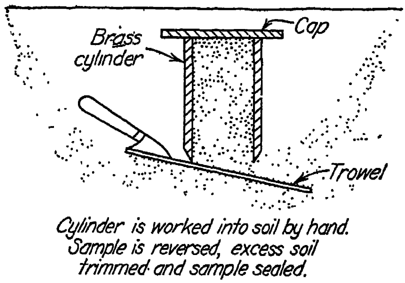



FIG. 38. Shallow sampling, cohesionless soil (sand). *Krynine, Soil Mechanics, McGraw-Hill Book Company.*

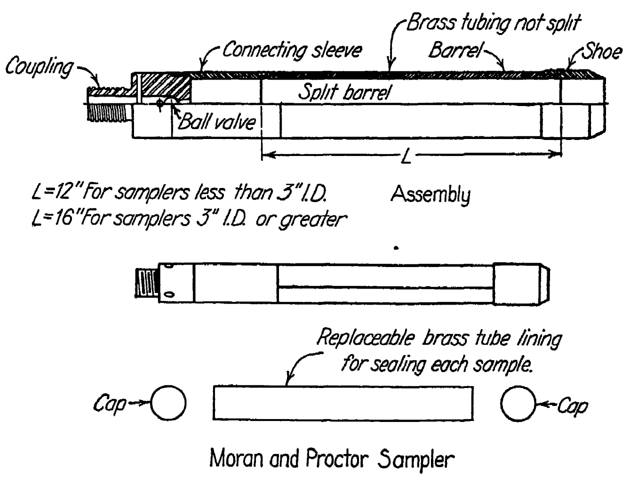



FIG. 39. Deep sampler, cohesive soils.

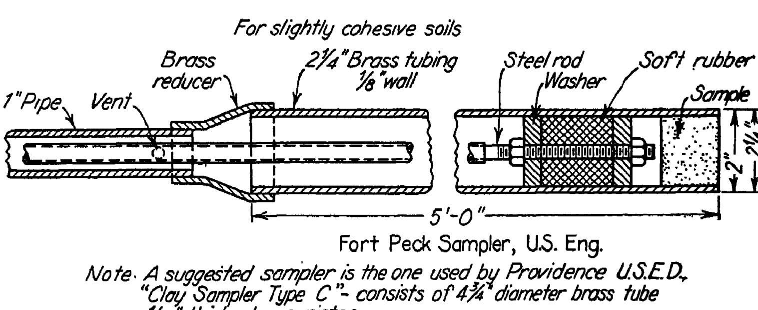
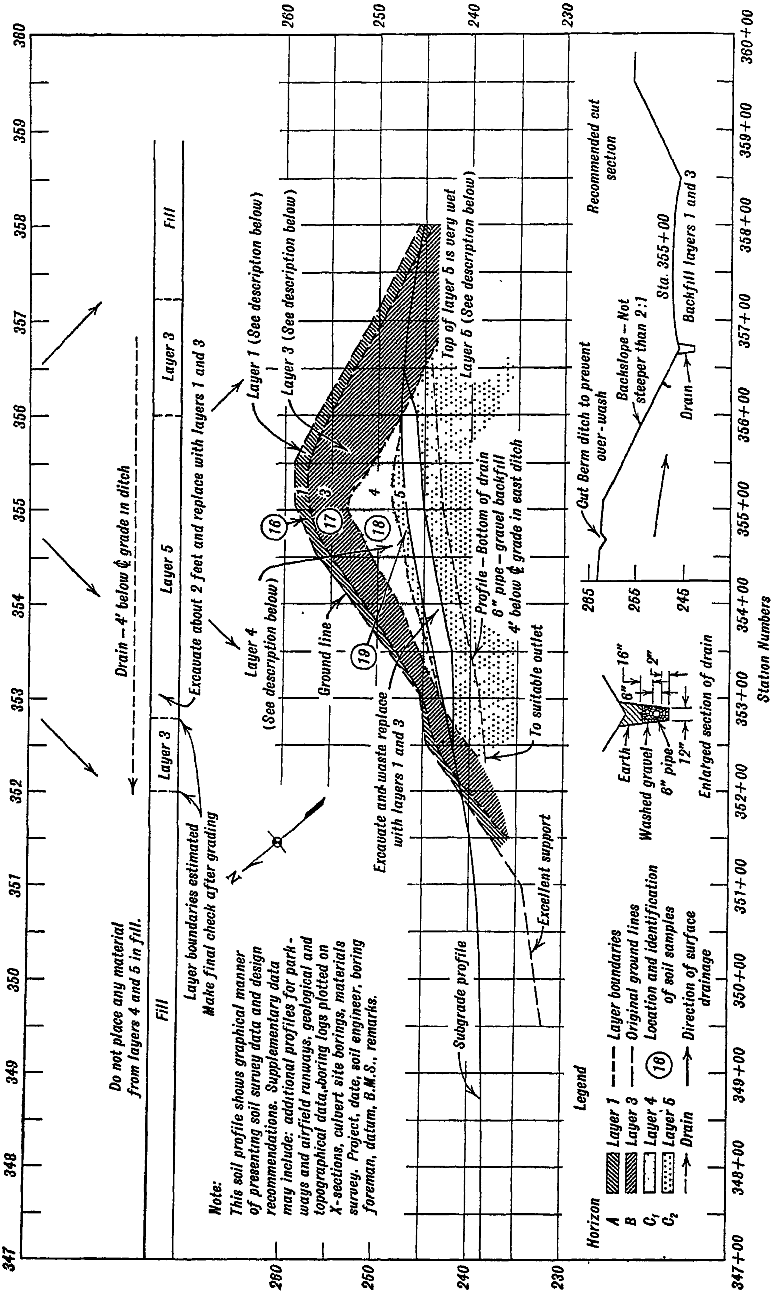



FIG. 40. Piston-type sampler, cohesive soils.



Do not place any material from layers 4 and 5 in fill.
Drain — 4' below ℄ grade in ditch
Fill
Layer 3
Layer 5
Layer 3
Fill
Layer boundaries estimated
Make final check after grading
Excavate about 2 feet and replace with layers 1 and 3
Note:
This soil profile shows graphical manner of presenting soil survey data and design recommendations. Supplementary data may include: additional profiles for parkways and airfield runways, geological and topographical data, boring logs plotted on X-sections, culvert site borings, materials survey. Project, date, soil engineer, boring foreman, datum, B.M.S., remarks.
N
Layer 4 (See description below)
Layer 1 (See description below)
Layer 3 (See description below)
Ground line
Excavate and waste replace with layers 1 and 3
16
17
18
19
1
3
4
5
Top of layer 5 is very wet
Layer 5 (See description below)
Profile — Bottom of drain
6" pipe — gravel backfill
4' below ℄ grade in east ditch
To suitable outlet
Subgrade profile
Excellent support
Legend
Horizon
A Layer 1
B Layer 3
$C_1$ Layer 4
$C_2$ Layer 5
Drain
Layer boundaries
Original ground lines
Location and identification of soil samples
Direction of surface drainage
Earth
Washed gravel
6" pipe
12"
6"
16"
2"
Enlarged section of drain
Cut Berm ditch to prevent over-wash
Backslope — Not steeper than 2:1
Sta. 355+00
Drain
Backfill layers 1 and 3
Recommended cut section
265
255
245
260
250
240
230
347
348
349
350
351
352
353
354
355
356
357
358
359
360
347+00
348+00
349+00
350+00
351+00
352+00
353+00
354+00
355+00
356+00
357+00
358+00
359+00
360+00
Station Numbers

*Results of Soil Tests*

| Identification Number | Layer | Mechanical Analysis: Per cent of particles having diameters smaller than 2 mm. | 0.5 mm. | 0.25 mm | 0.05 mm | 0.005 mm | 0.001 mm. |
|---|---|---|---|---|---|---|---|
| 16 | 1 | 100 | 100 | 98 | 90 | 28 | 19 |
| 17 | 3 | 100 | 98 | 96 | 85 | 19 | 14 |
| 18 | 4 | 53 | 49 | 44 | 42 | 19 | 13 |
| 19 | 5 | 100 | 98 | 96 | 99 | 73 | 50 |

*Physical properties of particles passing the 0.5 mm. sieve*

| Identification Number | Layer | Lower Liquid Limit | Plastic Index | Shrinkage Limit | Shrinkage Ratio | Moisture Equivalent Centrifuge | Moisture Equivalent Field | Group | Textural Class |
|---|---|---|---|---|---|---|---|---|---|
| 16 | 1 | 38 | 16 | 23 | 1.7 | 29 | 31 | A–4 | Silt loam |
| 17 | 3 | 27 | 18 | 18 | 1.7 | 36 | 22 | A–4 | Silty clay loam |
| 18 | 4 | 53 | 34 | 11 | 2.0 | 53* | 33 | A–7 | Clay and gravel |
| 19 | 5 | 101 | 71 | 14 | 1.9 | 93* | 58 | A–7 | Plastic clay |

*Waterlogged

Sample number 18 – Layer 4 contains coarse gravel. See description.

*General Notes and Recommendations*

Drainage is across the road from east to west
Original ground gives excellent support for fill
Layers 1 and 3 are excellent subgrade materials
Construct drain as shown on plan, profile, and cross section
Cut and waste layer 5 material to a depth of about 2 feet below grade and backfill with layers 1 and 3. See plan, profile, and cross section
Cut Berm ditch as shown in cross section
Cut backslopes not steeper than 2:1
Waste all material excavated from layers 4 and 5
Pavement design should include longitudinal and transverse crack control

*Description of Layers*

Layer 1.
Reddish brown mellow silt loam. Friable when dry but of pasty consistency when wet.

Layer 3
Grayish brown or mottled gray and rusty brown silty clay loam or silty clay of moderately compact structure. Compactness increases with depth. Friable when dry but plastic when wet. The compact nature of this layer does not seem to retard percolation to any degree.

Layer 4:
Similar to layer 5 but contains a very large quantity of gravel varying in size from 1/4" to 2" with the largest percentage between 3/4" and 1 1/2". The presence of gravel apparently does not affect the structure particles or their behaviour. On drying, shrinkage cracks develop and soil shrinks away from gravel. This layer also includes a brown or grayish brown compact clay which is a transition between layers 3 and 5, and shrinks considerably on drying.

Layer 5:
Mottled bluish gray and rusty brown plastic, sticky, and tenacious clay composed of angular structure particles which have a wet, shiny and slick surface. The particles are irregular in shape, easily crushed and when molded take on the appearance and consistency of putty. Upper 3 feet of layer is very wet. It blends gradually into a dense, plastic, cloddy structured bluish gray clay which retards the downward movement of water but does not stop it, since the water can penetrate between the cleavage planes which are well defined. White concretions, black, rusty brown and blood red stains are found throughout the layer. This material shrinks considerably on drying, leaving wide shrinkage cracks and on exposure the larger clods slake down to the smaller sized particles. This layer contains a high percentage of lime.

FIG. 41. Typical soil profile map as made for design and construction of road, runways, railroads, and canals. *Adapted from Surveying and Sampling Soils for Highway Subgrades, A.S.T.M.*

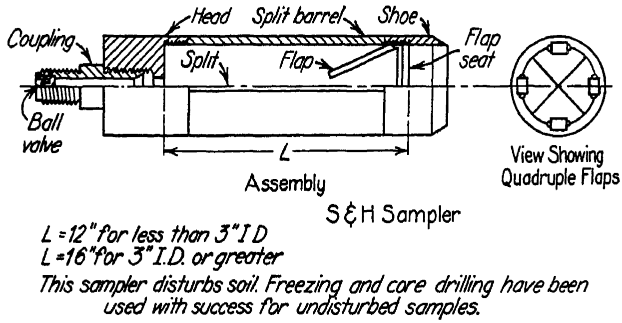
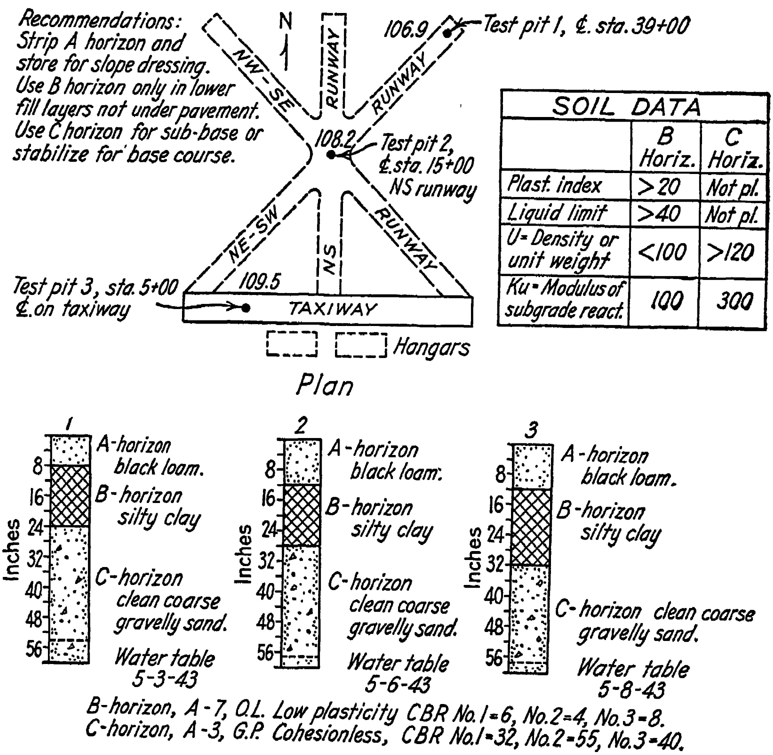



FIG. 42. Deep sampler, cohesionless soil. *Krynine, Soil Mechanics, McGraw-Hill Book Company.*




| SOIL DATA | B Horiz. | C Horiz. |
|---|---|---|
| Plast. index | >20 | Not pl. |
| Liquid limit | >40 | Not pl. |
| U = Density or unit weight | <100 | >120 |
| Ku = Modulus of subgrade react. | 100 | 300 |

FIG. 43. Plan and log of test pits for airfield.

## BORING LOG † (TYPICAL STRUCTURES)

Location *Antigua* Structure *Hangar (See key plan)* Sheet No *1* of *2*

Boring No *1* Datum ______ Boring Inspector *Smith* Date *1-3-41*

Miscellaneous Data:
*Length of hole 26'-0"*
*Rock 5'-0"*
*Weight of hammer 300 lbs*
*Aver. fall of hammer 30"*
*El. of ground water +68.4*

| Stratification: Elevation | Stratification: Depth | Stratification: Legend | | Description of Materials (Type, Color, & Consistency) | Casing: Blows | Casing: Penetration | Sample or Spoon: Blows | Sample or Spoon: Penetration | Sample No* | Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|
| *73.7* | *0* | | | *Surface* | | | | | | |
| | | | | *Brown sandy loam* | | | | | | *Few roots* |
| | | | *2'-6"* | *Trace of gravel* | | | *6* | *12"* | *1D* | *Dry and friable* |
| *71.2* | *2'-6"* | | | | | | | | | |
| | | | | | *8* | *12"* | *32* | *18"* | *2D* | *Fairly firm* |
| | | | | *Fine brown sand* | *10* | *12"* | | | | *Cohesionless* |
| *66'* | *G.W.* | | *6'-6"* | *Trace of gravel* | *16* | *12"* | | | | *Resistance* |
| | | | | | *16* | *12"* | *28* | *12"* | *3D* | *increases with* |
| *64.7* | *9'-0"* | | | | | | | | | *depth.* |
| | | | *2'-6"* | *Firm, hard, yellow,* | | | | | | *Becomes plastic* |
| | | | | *silty clay.* | *18* | *12"* | *20* | *18"* | *4D* | *when worked.* |
| *62.2* | *11'-6"* | | | | | | | | | |
| | | | | | | | | | | |
| | | | *9'-6"* | *Compact gravel, silt,* | *380* | *12"* | *60* | *3"* | *5D* | *Chips of black slate* |
| *52.7* | *21'-0"* | | | *and sand "Hardpan"* | | | | | | *embedded in silt.* |
| | | | | | | | | | | |
| | | | | *Buff-colored* | | | | | | *Casing and rods* |
| | | | *5'-0"* | *limestone.* | | | | | *6C* | *refused at 21'-0"* |
| | | | | *Hard 80% core* | | | | | | *Bottom of hole* |
| *47.7* | *26'-0"* | | | *recovery.* | | | | | | *at 26'-0."* |

*Note: Additional data may include: Key plan with contours, stations coordinates, and building outline; Benchmarks, date, drilling rig, casing dia.; length and diameter of sampler, Atterberg Limits, Mech. Analysis, density, water content.*

* *Write sample number at corresponding depth, designate dry samples by D, wash samples by W, undisturbed samples by U, and rock cores by C.*

** *When drilling cores in rock record the percentage of recovery in each foot of penetration.*

FIG. 44.

† *Caribbean Architect-Engineer.*

TABLE 30. MAJOR DIVISIONS OF SOILS

| Coarse-Grained (Granular) | | Fine-Grained | | Organic | |
|---|---|---|---|---|---|
| Gravel | Sand | Silt | Clay | Muck | Peat |

## IDENTIFICATION—VISUAL AND BY TEXTURE

### Gravel

Rounded or water-worn pebbles or bulk rock grains. No cohesion. No plasticity. Gritty and granular. Crunchy under foot. As a soil, over $\frac{1}{10}$ in. in size. As an aggregate, over $\frac{1}{4}$ in. in size.

### Sand

Granular, gritty, loose grains, passing No. 10 and retained on No. 270 sieve. Individual grains readily seen and felt. No plasticity or cohesion. When dry, a cast formed in the hands will fall apart. When moist, a cast will crumble when touched. The coarse grains are rounded; the fine grains are visible and angular. As an aggregate for construction sand consists of mineral grains between $\frac{1}{4}$ and $\frac{1}{200}$ in.

### Silt

Fine, barely visible grains, passing No. 270 sieve and over 0.005 mm. in size. Little or no plasticity. No cohesion. A dried cast is easily crushed in the hands. Permeable; movement of water through voids occurs easily and is visible. When mixed with water the grains will settle in from 30 minutes to 1 hour. Feels gritty when bitten. Will not form a ribbon. Care must be used to distinguish fine sand from silt and fine silt from clay.

### Clay

Invisible particles under 0.005 mm. (or 0.002 mm. in M.I.T. scale) in size. Cohesive. Highly plastic when moist. When pinched between the fingers will form a long, thin, flexible ribbon. Can be rolled into a thread to a pin point. When bitten with the teeth will not feel gritty. Will form hard lumps or clods when dry, difficult or impossible to crush in hands. Impermeable; no movement of water apparent through voids. Will remain suspended in water from 3 hours to indefinitely.

### Muck and Organic Silt

Thoroughly decomposed organic material with considerable mineral soil material. Usually black, with a few fibrous remains. Odorous when dried and burnt. Found as deposits in swamps, peat bogs, and muskeg. Easily identified. May contain some sand or silt.

### Peat

Partly decayed plant material. Mostly organic. Highly fibrous with visible plant remains.

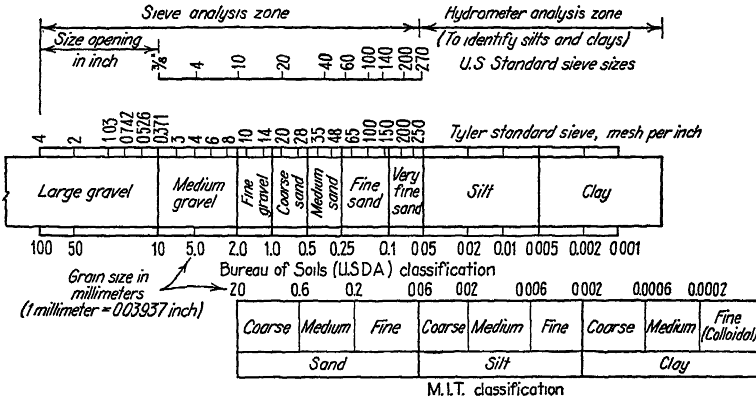



Fig. 45. Identification by mechanical grain size analyses.

*Notes.* Mechanical analysis is necessary to identify soils into the various divisions and into PRA and Casagrande systems. In general, the value of soils as a foundation for structures and as a material of construction is determined by the grain sizes and the gradation of the soil mixture. Other widely used grain-size classifications are International, M.I.T., Natl. Pk. Serv., A.S.T.M.

### Classification of Soils by Horizons

*Soil Profile:* A vertical cross section of the soil layers from the surface downwards.

The upper layer, surface soil or top soil. The upper part is designated $A_0$ and is humus or organic debris. Indices are used for subdivision into transition zones as shown for $A_1$, $A_2$, etc. May range to 24 in. in depth.

The heavier-textured underlayer or subsoil. May range from 6 in. to 8 ft. in depth. May be subdivided into transition zones $B_1$, $B_2$, etc., as shown. The products of the leaching or eluviation of the $A$ horizon may be deposited in horizon $B$.

The unweathered or incompletely weathered parent material.

The underlying stratum such as hard rock, hard pan, sand, or clay.

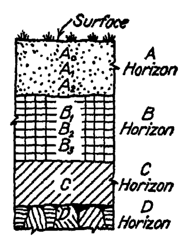



Fig. 46.

*Notes.* Structures or pavements are not usually placed on $A$ horizon soils. Also the organic content of these soils may adversely affect stabilization. In cuts the $C$ horizon soil does not usually have as good bearing value as the more weathered $B$ horizon. Foundations for heavy structures are preferably founded on the $D$ horizon where it is bedrock or unyielding.

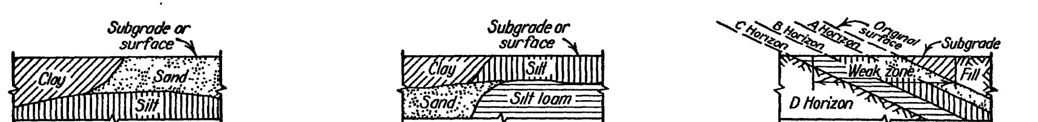
## P.R.A. CLASSIFICATION

### TABLE 31. CHARACTERISTICS FOR IDENTIFYING P.R.A. SOIL GROUPS *

Established by Public Roads Administration and Highway Research Board. Classification as shown is latest modification. Extensively used by engineers for highways, airfields, and dams.

| Characteristics \ Group | | A-1 | | A-2 | | A-3 | A-4 and A-4-7 † | A-5 and A-5-7 † | A-6 | A-7 | A-8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Non-Plastic | Plastic | Non-Plastic | Plastic | | | | | | |
| Textural Class | | Uniformly Graded Granular Coarse to Fine | | Poorly Graded Granular, Coarse, and Fine | | Clean Sand or Gravel | Silt or Silt Loam | Silt or Silt Loam | Plastic Clay | Plastic Clay Loam | Muck and Peat |
| Soil Constants | Internal friction | High | High | High | High | High | Variable | Variable | Low | Low | Low |
| | Cohesion | High | High | Low | High | None | Variable | Low | High | High | Low |
| | Shrinkage | Not detrimental | | Not significant | Detrimental if poorly graded | Not significant | Variable | Variable | Detrimental | Detrimental | Detrimental |
| | Expansion | None | | None | Some | Slight | Variable | High | High | Detrimental | Detrimental |
| | Capillarity | None | | None | Some | | Detrimental | High | High | High | Detrimental |
| | Elasticity | None | | None | Some | None | Variable | Detrimental | None | High | Detrimental |
| Capillary rise | | Low | High | 36″ max. | Over 36″ | 6″ max. | High | High | High | High | Detrimental |
| Atterberg Limits | Liquid limit | 25 max. | 35 max. | 35 max. | 40 max. | Non-plastic | 40 max. | Over 40 | 35 min. | 35 min. | 35–400 |
| | Plasticity index | 6 max. | 4–9 | Non-plastic | 15 max. | Non-plastic | 0–15 | 0–60 | 18 min. | 12 min. | 0–60 |
| | Shrinkage limit | 14–20 | | 15–25 | 25 max. | Not essential | 20–30 | 30–120 | 6–14 | 10–30 | 30–120 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Field moisture equivalent | | Not essential | Not essential | Not essential | Not essential | Not essential | 30 max. | 30–120 | 50 max. | 30–100 | 30–400 |
| Centrifuge moisture equivalent | | 15 max. | | 12–25 | 25 max. | 12 max. | Not essential | Not essential | Not essential | Not essential | Not essential |
| Shrinkage ratio | | 1.7–1.9 | | 1.7–1.9 | 1.7–1.9 | Not essential | 1.5–1.7 | 0.7–1.5 | 1.7–2.0 | 1.7–2.0 | 0.3–1.4 |
| Volume change | | 0–10 | | 0–6 | 0–6 | None | 0–16 | 0–16 | 17 min. | 17 min. | 4–200 |
| Lineal shrinkage | | 0–3 | | 0–2 | 0–4 | None | 0–4 | 0–4 | 5 min. | 5 min. | 1–30 |
| Grading (Grain Size) | % Sand | 70–85 | | 55–80 | 55–80 | 75–100 | 55 max. | 55 max. | 55 max. | 55 max. | 55 max. |
| | % Silt | 10–20 | | 0–45 | 0–45 | | High | Medium | Medium | Medium | Not significant |
| | % Clay | 5–10 | | 0–45 | 0–45 | | Low | Low | 30 min. | 30 min. | |
| | % Passing No. 10 | 20–100 | 40–100 | | | | | | | | |
| | % Passing No. 40 | 10–70 | 25–70 | | | | | | | | |
| | % Passing No. 200 | 3–25 | 8–25 | Less than 35 | Less than 35 | 0–10 | | | | | |




*Rapid succession of soil types, pockets of different soil types. Changes in soil profile or changes in soil structure.*
*Non-uniform support.*
Group B-1

*Adjacent parts of fills constructed of widely differing soil types, as where hauling is from different sources*
*Non-uniform support and settlement.*
Group B-2

*Cut through side hill creating subgrade on several types of natural soil and on fill within a short space*
*Non-uniform support and settlement.*
Group B-3

FIG. 47. Classification of non-uniform subgrade soils.

* *Adapted from Public Roads Administration and Highway Research Board Publications.*
† *A-4 or A-5 soil with A-7 characteristics.*

## TABLE 32. CLASSIFICATION OF SOIL MIXTURES *

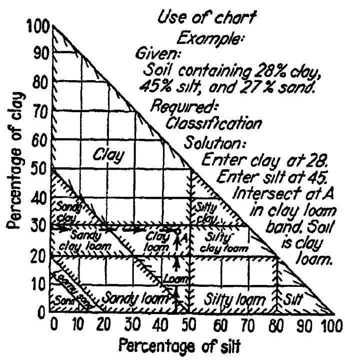



FIG. 48. Right angle soil chart.

| Class | Per Cent Sand | Per Cent Silt | Per Cent Clay |
|---|---|---|---|
| Sand | 80–100 | 0–20 | 0–20 |
| Sandy loam | 50–80 | 0–50 | 0–20 |
| Loam | 30–50 | 30–50 | 0–20 |
| Silt Loam | 0–50 | 50–100 | 0–20 |
| Sandy Clay Loam | 50–80 | 0–30 | 20–30 |
| Clay Loam | 20–50 | 20–50 | 20–30 |
| Silty Clay Loam | 0–30 | 50–80 | 20–30 |
| Sandy Clay | 55–70 | 0–15 | 30–45 |
| Clay | 0–55 | 0–55 | 30–100 |
| Silty Clay | 0–15 | 55–70 | 30–45 |

* *Adapted from Soil Cement Laboratory Handbook, Portland Cement Assoc.*

*Note.* Determine proportions of sand, silt and clay by sieve analysis or inspection.

(Natural soils seldom exist separately as gravel, sand, silt, clay, but are found as mixtures.)

## TABLE 33. CLASSIFICATION OF SOILS BY ORIGIN

| | | |
|---|---|---|
| Residual: | | Rock weathered in place—Wacke, laterite, podzols, residual sands, clays and gravels. |
| Cumulose | | Organic accumulations—peat, muck, swamp soils, muskeg, humus, bog soils. |
| Transported | Glacial | Moraines, eskers, drumlins, kames—till, drift, boulder clay, glacial sands and gravels. |
| Transported | Alluvial | Flood planes, deltas, bars—sedimentary clays and silts, alluvial sands and gravels. |
| Transported | Aeolian | Wind-borne deposits—blow sands, dune sands, loess, adobe. |
| Transported | Colluvial | Gravity deposits—cliff debris, talus, avalanches, masses of rock waste. |
| Transported | Volcanic | Volcanic deposits—Dakota bentonite, volclay, volcanic ash, lava. |
| Transported | Fill | Man-made deposits—may range from waste and rubbish to carefully built embankments. |

*Note.* In general, residual or glacial deposits are preferable for heavy foundations. Important in soil surveys and engineering reports.

## ATTERBERG LIMIT TESTS

**Purpose.** 1. To classify soils into P.R.A. or Casagrande Groups. 2. To assign soils a value as a foundation or construction material. 3. Construction control and laboratory reports. High values of L.L. and P.I. indicate high compressibility and low bearing capacity. High shrinkage values indicate excessive volume change.

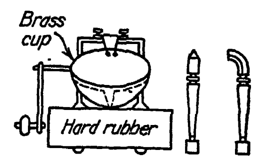
The liquid limit (L.L.) of a soil is the water content at which the groove formed in a soil sample with a standard grooving tool will just meet when the dish is held in one hand and tapped lightly 10 blows with the heel of the other hand. In the machine method the L.L. is the water-content when the soil sample flows together for ½" along the groove with 25 shakes of the machine at 2 drops per sec.

Diameter of brass cup or evaporating dish about 4½ in.

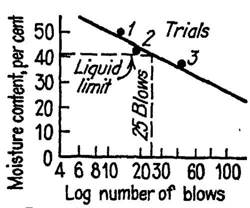
Size of sample: By hand 30 grams; by machine 100 grams.

Several trials are made, the moisture content being gradually increased. Blows are plotted against water content and the liquid limit is picked off from the curve as shown, or

$$\text{L.L.} = \frac{\text{Weight of water}}{\text{Weight of oven-dried soil}} \times 100$$

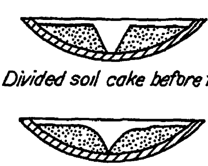


Casagrande Liquid Limit Machine



Example of Flow Curve

*Adapted from Krynine, Soil Mechanics, McGraw-Hill Book Company.*




*Adapted from Hogentogler, Engineering Properties of Soil, McGraw-Hill Book Company.*

FIG. 49. Liquid limit (L.L.), A.S.T.M. 0423, A.A.S.H.O. T-89.

The plastic limit (P.L.) is the lowest water-content at which a thread of the soil can be just rolled to a diam. of ⅛ in. without cracking, crumbling, or breaking into pieces.

$$\text{P.L.} = \frac{\text{Weight of water}}{\text{Wt. of oven-dried soil}} \times 100$$

Size of soil sample is 15 grams.

Soil which cannot be rolled into a thread is recorded as non-plastic (N.P.):

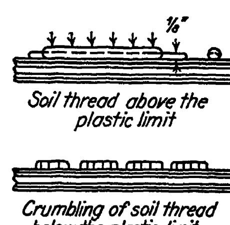



FIG. 50. Plastic limit (P.L.), A.S.T.M. D424, A.A.S.H.O. T-90.

## TABLE 34. LIMITING VALUES

| Base Course | Subgrade | Sub-base | Stab. Surf. | Soil Cement | Cem. Treated Base |
|---|---|---|---|---|---|
| No Shrinkage L.L. = 25 P.I. = 6 max. | Lineal Shrinkage 3% to 5% | L.L. = 35 P.I. = 15 max. | P.I. = 4 to 9 | L.L. = 40 P.I. = 18 max. | L.L. = 25 P.I. = 6 to 9 |

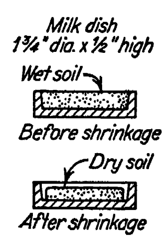
The water content or moisture content is expressed as a percentage of the oven-dried weight of the soil sample. These soil constants are determined from the soil fraction passing the No. 40 (420-micron) sieve.

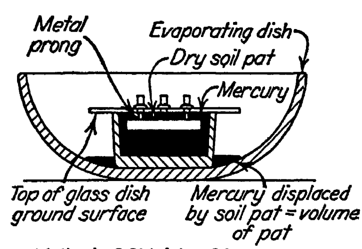
---

*Plasticity Index* (*P.I.*): A.A.S.H.O., T-91. Numerical difference between liquid limit (L.L.) and plastic limit (P.L.) or P.I. = L.L. − P.L. Example: Given L.L. = 28, P.L. = 24, P.I. = 4. Cohesionless soils are reported as non-plastic (N.P.). When plastic limit is equal to or greater than liquid limit the P.I. is reported as 0, see Table 31.

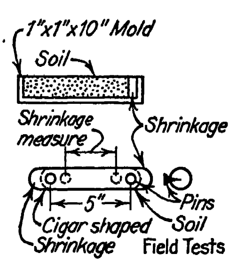
*Shrinkage Ratio* (*R*): = bulk specific gravity of the dried soil pat used in obtaining shrinkage limit.

$$R = \frac{\text{Weight of oven-dried soil pat in grams}}{\text{Volume of oven-dried soil pat in cc.}} \quad \text{or} \quad \frac{W_0}{V_0}$$




Method of Obtaining Displaced Mercury




*Shrinkage Limit*(*s*): A.S.T.M., A.A.S.H.O., T-92. Water content at which there is no further decrease in volume with additional drying of the soil but at which an increase in water content will cause an increase in volume.

$$S = \left(\frac{1}{\text{Shrinkage ratio}} - \frac{1}{\text{Spec. gravity}}\right) \times 100.$$

Size of sample 30 grams.

*Lineal Shrinkage* is the decrease in one dimension of the soil mass when the water content is reduced to the shrinkage limit or the % change in length occurring when a moist sample has dried out.

## MOISTURE DETERMINATION

**Purpose:** 1. To determine moisture content for optimum moisture and maximum density relations. 2. To determine the amount of water in aggregates for concrete, bituminous, and other mixtures.

*Gravelly soils:* Use pycnometer method, Fig. 51, or heat method described below.

*Sandy soils:* Use Chapman flask, Fig. 52, or heat method described below.

*Silts and clays:* Use heat method described below.

**Heat Method:** For total moisture content or surface moisture content.

1. Obtain a representative sample. If a metric scale is available the sample should not be smaller than 100 grams. If an avoirdupois scale graduated by ½ ounces is used, the sample should contain at least 50 ounces.

2. Weigh sample and record weight.

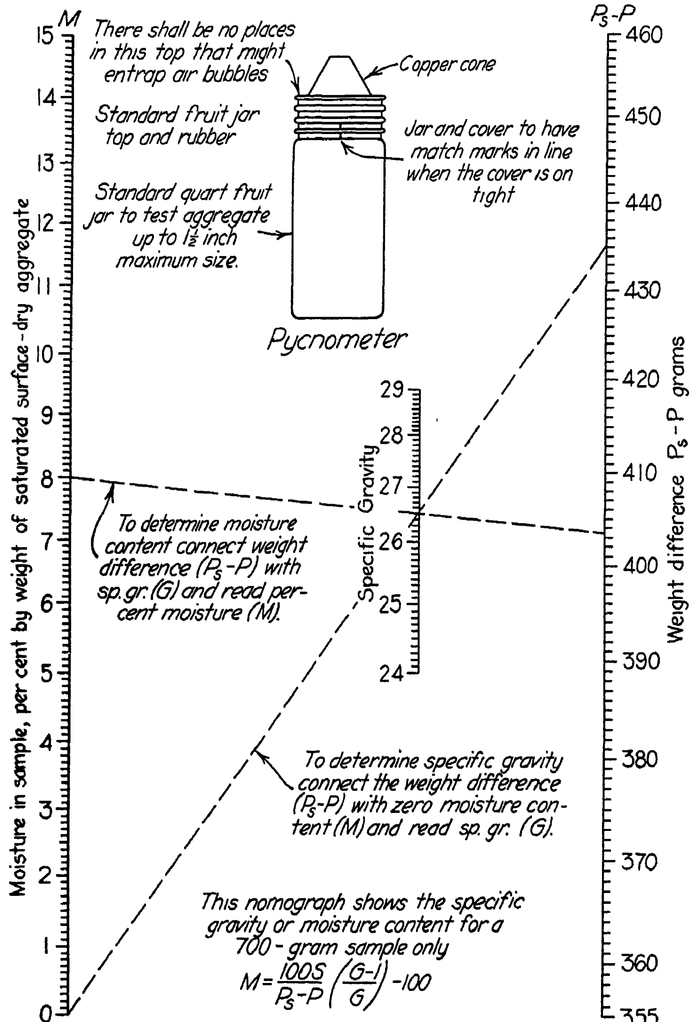
3. Place sample in pan and spread to permit uniform drying. Set pan in oven or on top of stove in a second pan to prevent burning of soil.

4. Dry to constant weight when total moisture is to be found; dry until surface moisture disappears when surface moisture content is desired. Temperature should not exceed 105° C. (221° F.). Stir constantly to prevent burning.

5. After the sample has been dried to constant weight, remove from oven and allow to cool sufficiently to permit absorption of hygroscopic moisture. Weigh dried sample and record weight.

6. Compute the moisture content as follows:

$$\text{Per cent moisture} = \frac{\text{weight of wet soil} - \text{weight of dry soil}}{\text{weight of dry soil}} \times 100$$




*M*, *moisture in sample, percent by weight of saturated, surface-dry aggregate.*
*S*, *weight of moist-sand sample = 700 grams for use with this nomograph.*
*P*, *weight of the pycnometer full of water, grams.*
$P_s$, *weight of the pycnometer containing the sample and filled with water, grams.*
*G*, *specific gravity of the aggregate, saturated and surface-dry.*

FIG. 51. Specific gravity and surface moisture content of aggregate, pycnometer method.

*Use of the Chapman Flask:*

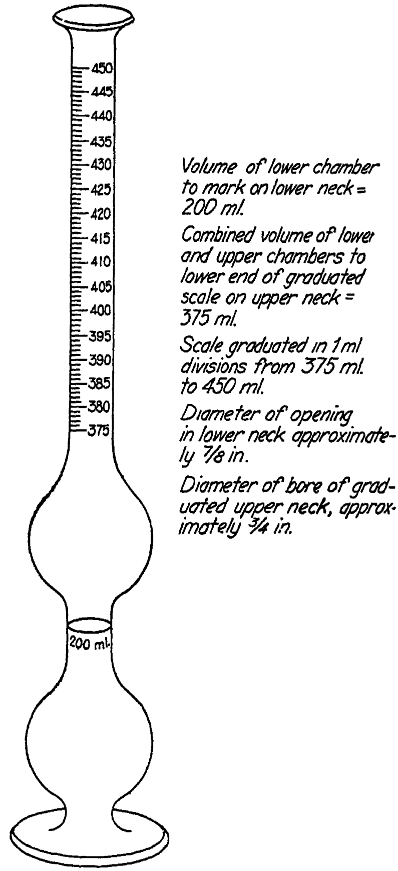
Fill to the 200-ml. mark on the lower neck with water. Add 500 grams of moist soil and read the combined volume = $V$ on upper scale. $M$ = approximate percentage of surface moisture.

$$M = \frac{V - \dfrac{500}{\text{sp. gr.}} - 200}{200 + 500 - V} \times 100$$

Sp. gr. = the bulk specific gravity of the surface dry aggregate found by the equation $500 \div (V' - 200)$.

$V'$ differs from $V$ in that 500 grams of dry sample is added instead of 500 grams of a moist sample as in the case of $V$. This method is only practical for the surface moisture of relatively sandy soils.

Use stirring rod to eliminate air.




Chapman Flask*

*Note: Use with caution on account of absorbed air present.*

FIG. 52. Specific gravity and surface moisture content of aggregate, Chapman flask method.

## MAXIMUM DENSITY, OPTIMUM MOISTURE, PROCTOR NEEDLE PLASTICITY TEST

**Purpose** of maximum density-optimum moisture test is to determine the percentage of moisture at which the maximum density can be obtained when soil is compacted in fill, earth dams, embankments, etc.

After the maximum density curve has been obtained, these samples may be subjected to the Proctor needle for resistance to penetration.

* *From A.S.T.M. Specifications.*

Then subjecting soil at the site to the Proctor needle, the amount of compaction of soil at the site may be obtained. See Fig. 55(a).

**Maximum Density, Optimum Moisture, as per A.S.T.M.-D698-A.A.S.H.O.-D: T-99.**

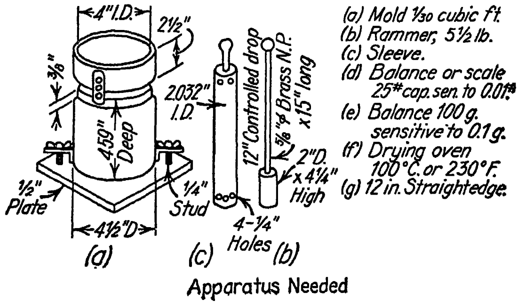



FIG. 53.

**Testing Procedure.** 6 lb. ± (3000 grams) of air-dried soil slightly damp and passing the No. 4 sieve is mixed thoroughly, then compacted in the mold in 3 equal layers, each layer receiving 25 blows from the rammer with a controlled drop of 1 ft. The collar is removed, the soil struck off level and the mold weighed.

(Wt. of soil plus mold − wt. of mold) × 30

= wet weight per cubic foot or wet density

A 100-g. sample from the center of the mold is weighed, then dried at 230° F., and the moisture content is determined.

Pulverize 6-lb. sample, add about 1% water, and repeat test. Repeat until soil becomes saturated (about 5 times). Plot wet-density curve. See Fig. 54. Compute dry density by formula and plot curve:

$$\text{Dry density} = \frac{\text{Wet wt., lb. per cu. ft.}}{\%\ \text{moisture} + 100} \times 100$$

In Fig. 54 enter at top of dry density curve and read optimum moisture and maximum weight of soil 20.2% and 103.5 lb.

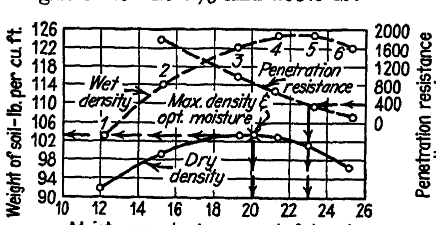



FIG. 54.

## Modified A.A.S.H.O. Method.*

Same as above except:
1. Rammer to weigh 10 lb.
2. Rammer to have controlled drop of 18 in.
3. Soil compacted in mold in 5 equal layers, 25 blows to each layer.

The highest dry density is recorded as laboratory unit weight.

**Note.** Modern air field compaction equipment can secure greater densities than can be obtained by the standard Proctor or A.A.S.H.O. Test. If field compaction or vibration will give greater densities on any job than the test, the higher density should be used to control compaction.

## Proctor Needle Plasticity Test †

Five pounds of dry soil passing a No. 10 sieve is mixed thoroughly with just enough water to make it slightly damp, then compacted in the mold in 3 layers. Each layer is given 25 blows with the rammer dropped 1 ft. The soil is then struck off level with the cylinder, weighed, and the stability determined with the plasticity needle by measuring the force required to press it into the soil at the rate of ½ in. per sec. A small portion of the soil is oven-dried to determine the moisture content. This procedure is repeated 3 to 6 or more times, each time adding about 1% more water until the soil becomes very wet. The density and plasticity needle readings are plotted against moisture content. See Fig. 54. Thu in Fig. 54 a needle reading of 400 gives a moisture content of 23%.

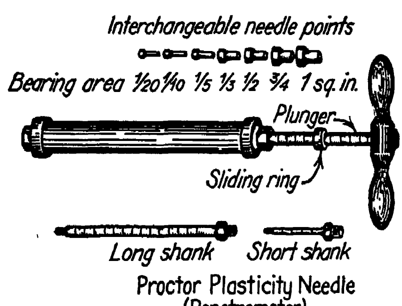
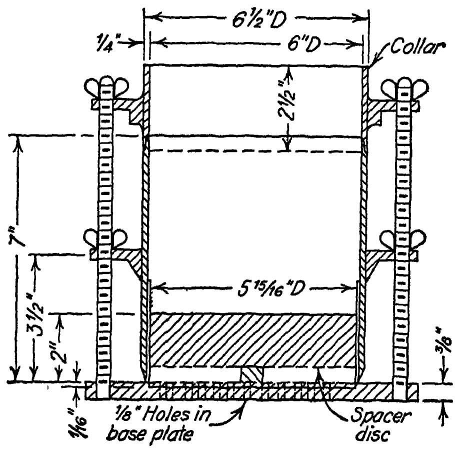



FIG. 55(a).

* *Engineering Manual, O.C.E., War Dept.*

† *Engineering News-Record, Aug. 31 to Sept. 28, 1933, R. R. Proctor.*




CBR Mold

Fig. 55(b). Apparatus.

## California Bearing Ratio

**Purpose** is to obtain relative resistance of a soil in place or soil to be placed and compacted to a specified degree to a standard broken stone layer. The resistance of the standard layer is given in the last column of the report form for California bearing ratio on p. 130.

For soil in place apply a 3 sq in. end area piston at a constant rate of penetration of 0.05 in. per minute to a total penetration of 0.5 in. The penetration force required per square inch at the values in the left-hand column of the report form for California bearing ratio on p. 130 is recorded and stated as a ratio of the corresponding values in the right-hand column of the report; usually the values for 0.1-in. deflection are used.

Laboratory determination is made by remolding the samples of the soil until it has the specified density using the A.S.T.M. or A.A.S.H.O. methods given above, except that 55 blows of the rammer are used instead of 25 and material is passed through a ¾-in. sieve instead of a No. 4 sieve. These samples are then loaded by means of the same piston and recorded as given above for the field test.

For the purpose of determining the effect of saturating conditions on the soil, tests may be made on soaked samples.

## FIELD DENSITY (UNIT WEIGHT) TEST *

**Purpose.** 1. To obtain the natural density of soil in place (*a*) as an indication of its stability or bearing value as foundation, (*b*) to compute

* *Adapted from Public Roads, Vol. 22, No. 12 by Harold Allen, Public Roads Administration.*

the shrinkage or swell when the soil is removed and placed in embankment at a higher or lower density. 2. To determine the per cent of compaction being obtained to check against requirements of specifications.

## Method of Determining Weight per Cubic Foot of Soil in Place. Calibrated Sand Method

The density of a soil layer may be determined by finding the weight of a disturbed sample and measuring the volume of the space occupied by the sample prior to removal. This volume may be measured by filling the space with a weighed quantity of a medium of predetermined weight per unit volume. Sand, heavy lubricating oil, or water in a thin rubber sack may be used.

1. Determine the weight per cubic foot of the dry sand by filling a measure of known volume. The height and diameter of the measure should be approximately equal, and its volume should be not less than 0.1 cu. ft. The sand should be deposited in the measure by pouring through a funnel or from a measure with a funnel spout from a fixed height. The measure is filled until the sand overflows and the excess is struck off with a straightedge. The weight of the sand in the measure is determined, and the weight per cubic foot computed and recorded.

2. Remove all loose soil from an area large enough to place a box similar to the one shown in Fig. 57 and cut a plane surface for bedding the box firmly. A dish pan with a circular hole in the bottom may be used.

3. With a soil auger or other cutting tools bore a hole the full depth of the compacted lift.

4. Place in pans all soil removed, including any spillage caught in the box. Remove all loose particles from the hole with a small can or spoon. Extreme care should be taken not to lose any soil.

5. Weigh all soil taken from the hole, and record weight.

6. Mix sample thoroughly, and take sample for water determination.

7. Weigh a volume of sand in excess of that required to fill the test hole, and record weight.

8. Deposit sand in test hole by means of a funnel or from a measure as illustrated in Fig. 57 by exactly the same procedure as was used in the determination of unit weight of sand until the hole is filled almost flush with original ground surface. Bring the sand to the level of the base course by adding the last increments with a small can or trowel and testing with a straightedge.

9. Weigh remaining sand, and record weight.

10. Determine the moisture content of soil samples in percentage of dry weight of sample.

11. Compute dry density from the following formulas:

$$\text{Vol. soil} = \frac{\text{Wt. of sand to replace soil}}{\text{Wt. per cu. ft. of sand}}$$

$$\%\ \text{moisture} = \frac{\text{Wt. of moist. soil—Wt. of dry soil}}{\text{Wt. of dry soil}} \times 100$$

$$\text{Moist density} = \frac{\text{Weight of soil}}{\text{Volume of soil}}$$

$$\text{Dry density} = \frac{\text{Moist density}}{1 + \dfrac{\%\ \text{of moisture}}{100}}$$

$$\%\ \text{compaction} = \frac{\text{Dry density}}{\text{Maximum density}} \times 100$$

EXAMPLE. *Given:*

| | | |
|---|---|---|
| Wt. per cubic foot of sand | = | 100 lb. |
| Wt. of moist soil from hole | = | 5.7 lb. |
| Moisture content of soil | = | 15% |
| Wt. of sand to fill hole | = | 4.5 lb. |

*Required:* Density and per cent compaction.

*Solution:* $\text{Vol. soil} = \dfrac{4.5}{100} = 0.045$ cu. ft.

$$\text{Moist density} = \frac{5.7}{0.045} = 126.7 \text{ lb.}$$

$$\text{Dry density} = \frac{126.7}{1 + 15/100} = 110.0 \text{ lb.}$$

Given maximum density = 115 lb. (from density test).

$$\%\ \text{compaction} = \frac{110}{115} \times 100 = 95.7\%$$

*Note.* In gravel soils material over ¼ in. is screened out and correction made.

*Chunk Sample Method.* 1. Cut sample 4″–5″ in diameter full depth of layer. 2. Determine per cent moisture. 3. Trim sample and weigh to ½ oz. 4. Immerse sample in hot paraffin, remove, cool, and weigh again. 5. Compute volume of paraffin using 55 lb. per cu. ft. 6. Compute volume of sample by weighing in water (correcting for volume of paraffin). 7. Compute density data by formulas above.

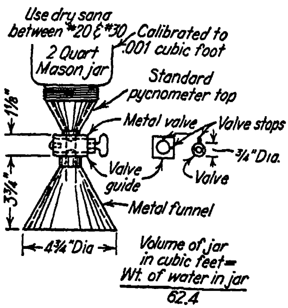



FIG. 56. Field density determination apparatus, dry sand method.

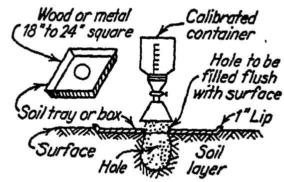



FIG. 57. Field density test.

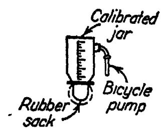



FIG. 58. Rubber sack inflated to fill hole with known volume of water.

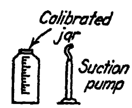



FIG. 59. Pump and jar to fill hole with known volume of oil. S.A.E.-40.

**TABLE 35. BEARING VALUES AND PER CENT COMPACTION REQUIRED**

| Max. Dry Density | Soil Rating | Recommended Compaction |
|---|---|---|
| 90 lb. and less | No good | |
| 90 lb.–100 lb. | Very poor | 95–100% |
| 100–110 lb. | Poor to very poor | 95–100% |
| 110–120 lb. | Poor to fair | 90–95% |
| 120–130 lb. | Good | 90–95% |
| 130 lb. and over | Excellent | 90–95% |

*Note.* Density or $\frac{\text{Wt.}}{\text{Vol.}}$ may be expressed as pound per cubic foot or grams per cubic centimeter. Density in grams per cubic centimeter = bulk specific gravity.

## MECHANICAL ANALYSIS (GRAIN SIZE)

**Purpose.** 1. To identify homogeneous soils in the major divisions. See pp. 108 and 109. 2. To classify soil mixtures occurring in a natural state, Table 32 & Fig. 46. 3. To classify soil into the P.R.A. or Casagrande groups. See pp. 110 and 111, also Vol. I, p. 3-06. 4. To design or control stabilized soil mixtures. 5. To determine frost heaving potentialities. 6. To determine effective size ($D_{10}$) and uniformity coefficient ($Cu$) for the design and control of filters and subdrainage backfill.

### Sieve Analysis

Size of sample to be 400 to 750 grams—the coarser the material the larger the sample required.

Take sample by quartering or with sample splitter.

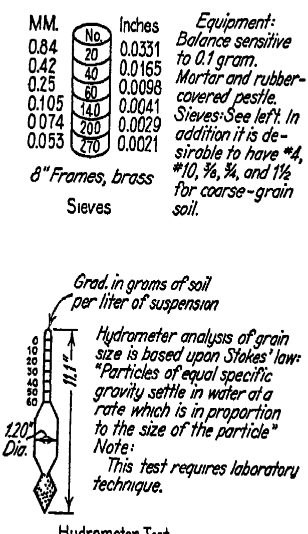



FIG. 60. Mechanical analysis of soils.

Dry surface moisture by heating the quartered sample at less than 212° F., or boiling point of water at high altitudes, in open pan until surface water disappears and sample is apparently dry and will not lose more weight with additional heating.

Break up cakes with mortar and pestle.

Record dry weight of sample.

Proceed to pass material through screens by placing sample in a stack of sieves, largest size on top, and shake vigorously with horizontal rotating motion balancing on bumper or pad until no more material will pass through each screen.

Weigh amount retained on each sieve, compute per cent of total weight of sample, and plot curve.

Washing is recommended for No. 200 sieves and smaller.

Partly immerse the largest sieve in a pan of water and agitate.

Take material and water from pan and repeat for next smaller size sieve. Agitate smallest sieve in several water baths until water remains clear. Air-dry portions retained in sieves, weigh, and plot curve.

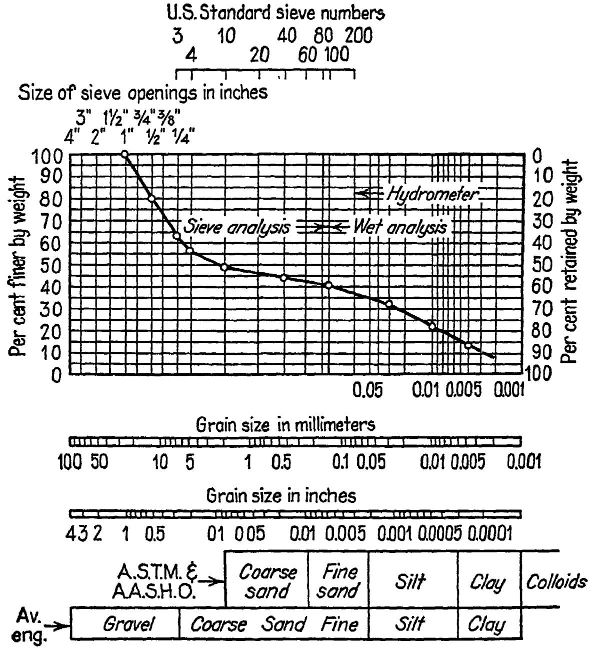



FIG. 61. Typical grain size curve.

**Effective size** ($D_{10}$) of a soil is the particle size that is coarser than 10% (by weight) of the soil; that is, 10% of the soil consists of particles smaller than the effective size ($D_{10}$) and 90% consists of larger particles. *Example.* In Fig 62, effective size ($D_{10}$) is 0.02 mm.

**Uniformity coefficient** ($Cu$) is computed by first determining the size that is coarser than 60% of the soil and dividing that size by the effective size ($D_{10}$), i.e., $Cu = \dfrac{60\%\ \text{size}}{10\%\ \text{size}}$.

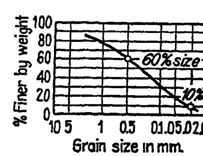



FIG. 62. Effective size ($D_{10}$) and uniformity efficient ($Cu$).

*Example.* In chart, $Cu = \dfrac{0.5}{0.02} = 25$.

*Note.* The $Cu$ of filter backfill should not be over 20. The $D_{10}$ of non-frost heaving uniform soil is 0.02 mm. minimum.

Engineer

## OPTIMUM MOISTURE—MAXIMUM DENSITY

### Laboratory Test

Location ______________ Soil sampler ______________

Date ______________ Soil tester ______________

Control soil #

| Item | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 |
|---|---|---|---|---|---|---|
| Weight of cylinder + wet soil | | | | | | |
| Weight of cylinder | | | | | | |
| Weight of wet soil | | | | | | |
| Weight of wet sample + pan | | | | | | |
| Weight of pan | | | | | | |
| Weight of wet sample | | | | | | |
| Weight of dry sample + pan | | | | | | |
| Weight of pan | | | | | | |
| Weight of dry sample | | | | | | |
| Weight of moisture | | | | | | |
| % of moisture | | | | | | |
| Wet density | | | | | | |
| Dry density | | | | | | |

Optimum moisture = Maximum density =

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Engineer

TUTTLE, SEELYE, PLACE & RAYMOND

*Report on Density Determination*

| | | | |
|---|---|---|---|
| Test No. | ____ | Date | ____ |
| Location | ____ | Depth | ____ |
| Soil sampler | ____ | Density of standard sand | ____ lb. per sq. ft. |

### Field Test

Weight of sand and container ____ lb.
Weight of sand and container (remaining) ____ lb.
Weight of sand to fill hole and funnel ____ lb.

Volume of field sample =

$$\frac{\text{weight of sand to fill hole and funnel}}{\text{density of standard sand}} - \text{volume of sand in funnel} \;\_\_\_\_\text{ cu. ft.}$$

Weight of field sample (moist) and container ____ lb.
Weight of container ____ lb.
Weight of field sample (moist) ____ lb.

### Laboratory Test

*Soil Tester* *Date*

Weight of laboratory sample (moist) and container ____ g.
Weight of container ____ g.
Weight of laboratory sample (moist) ____ g.
Weight of laboratory sample (dry) and container ____ g.
Weight of container ____ g.
Weight of laboratory sample (dry) ____ g.
Weight of moisture in laboratory sample ____ g.

$$\%\text{ moisture} = \frac{\text{weight of moisture in lab. sample}}{\text{weight of lab. sample (dry)}} \times 100 \quad = \_\_\_\_\ \%$$

$$\text{Field density} = \frac{\text{weight of field sample (moist)}}{\text{volume of field sample } (1 + \%\text{ moisture})} \quad = \_\_\_\_\text{ lb. per cu. ft.}$$

$$\%\text{ compaction} = \frac{\text{field density}}{\text{maximum density}} \times 100$$

$$= \_\_\_\_\ \%$$

Computed by ____________________ Checked by ____________________

____________________
Engineer

SOIL STUDIES *

Report for ____________________ Date ________
Material ____________________ Report No. ________
Project ____________________

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sample identification | | | | | | | Location of Samples |
| Classification | | | | | | | |
| Hygroscopic moisture | | | | | | | |
| Gradation<br>*Pass.* / *Ret.*<br>1″ / ¾″<br>¾″ / ½″<br>½″ / 4 mesh<br>4 / 10<br>10 / 20<br>20 / 40<br>40 / 60<br>60 / 100<br>100 / 200<br>200 (wash) | | | | | | | |
| Hydrometer test<br>% Finer #10<br>#200<br>0.005 mm.<br>0.001 mm. | | | | | | | Remarks: |
| Liquid limit | | | | | | | |
| Plastic limit | | | | | | | |
| Plastic Index | | | | | | | |
| Specific gravity | | | | | | | |

| Absorption and Stability Tests of Materials Used | Opt. Mois. | Density Wt./cu. ft. | % Blended Soil | % Water | % Binder | 7-day Absorp. % | 7-day Stab. (lb.) Bottom ½-in. |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

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Inspector

* *From Haller Engineering Associates, Inc.*

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Engineer

SOILS CLASSIFICATION *

Client ________________________ Date ____________
Report No. ____________

| | | | | |
|---|---|---|---|---|
| Site | | | | |
| Sample No. | | | | |
| Location | | | | |

SOIL TYPE

| Size (mm.) | % | % | % | |
|---|---|---|---|---|
| Gravel 2.0 + | | | | |
| Sand 2.0 − 0.05 | | | | |
| Silt 0.05 − 0.005 | | | | |
| Clay 0.005 − | | | | |

SIEVE ANALYSIS

| Sieve Size | Diameter (mm.) | % Passing | % Passing | % Passing | % Passing |
|---|---|---|---|---|---|
| 2″ | 50.80 | | | | |
| 1½″ | | | | | |
| 1″ | 26.67 | | | | |
| ¾″ | 18.85 | | | | |
| ⅜″ | 9.423 | | | | |
| No. 4 | 4.699 | | | | |
| No. 10 | 1.981 | | | | |
| No. 40 | 0.417 | | | | |
| No. 60 | 0.246 | | | | |
| No. 100 | 0.147 | | | | |
| No. 200 | 0.074 | | | | |

HYDROMETER ANALYSIS

| Size of Particle | % Smaller than | % Smaller than | % Smaller than | % Smaller than |
|---|---|---|---|---|
| 0.05 mm. | | | | |
| 0.005 mm. | | | | |
| 0.001 mm. | | | | |

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Inspector

* *From Haller Engineering Associates, Inc.*

______________________
Engineer

CALIFORNIA BEARING RATIO *

Client ______________________ Date ______________
Report No. ______________

Site

| | | | | |
|---|---|---|---|---|
| Sample No. | | | | |
| Location | | | | |

MAXIMUM DENSITY, OPTIMUM MOISTURE

| | | | | |
|---|---|---|---|---|
| Optimum water content (percentage of dry weight) | | | | |
| Maximum density (pounds per cu. ft.) | | | | |

CALIFORNIA BEARING TEST DATA

| Condition of Sample | | | | | | | |
|---|---|---|---|---|---|---|---|
| Penetration (inches) | Lb. per Sq. In. | C/B Ratio | Lb. per Sq. In. | C/B Ratio | Lb. per Sq. In. | C/B Ratio | Standard |
| 0.025 | | | | | | | |
| 0.050 | | | | | | | |
| 0.075 | | | | | | | |
| 0.10 | | | | | | | *1000* |
| 0.20 | | | | | | | *1500* |
| 0.30 | | | | | | | |
| 0.40 | | | | | | | |
| 0.50 | | | | | | | |
| Unit dry weight (pounds per cu. ft.) | | | | | | | |
| Expansion % | | | | | | | |

WATER CONTENTS—PERCENTAGE OF DRY WEIGHT

| | | | | |
|---|---|---|---|---|
| Unsoaked | | | | |
| Soaked—Top 1 in. | | | | |
| Soaked—Total | | | | |

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Inspector

* *Adopted from Haller Engineering Associates, Inc.*

BORING LOG *

Location ______ Structure ______ Sheet No. ___ of ___

Boring No. ___ Datum ____ Boring inspector ____ Date ______

| Stratification | | | Description of Materials (Type, Color, and Consistency) | Casing | | Sampler or Spoon | | Sample No. † | Remarks ‡ |
|---|---|---|---|---|---|---|---|---|---|
| Elevation | Depth | Legend | | Blows | Penetration | Blows | Penetration | | |
| | | | | | | | | | |
| | | | | | | | | | |
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| | | | | | | | | | |

† Write sample number at corresponding depth. Designate dry samples by *D*, wash samples by *W*, undisturbed samples by *U*, rock cores by *C*.

‡ When drilling cores in rock, record the percentage of recovery in each foot of penetration.

* *From Caribbean Architect-Engineer.*

BORING LOG (Continued)

Location of project ____________________

Location of boring ____________________

Coordinates ____________ and ____________

Drill No. ________

Boring foreman ____________

Size and weight of casing ____________ Depth ________

____________ ________

Length of hole ________ Earth ________ Rock ________

Type of rock drill used ____________________

Weight of hammer ____________

Average fall of hammer ____________

Elevation of ground water surface ____________

Record of Work

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Date | | | | | | | |
| Start | | | | | | | |
| Finish | | | | | | | |
| Hours | | | | | | | |
| Total Depth | | | | | | | |
| Weather | | | | | | | |
| Temperature | | | | | | | |

Boring inspector ____________

Remarks ____________________

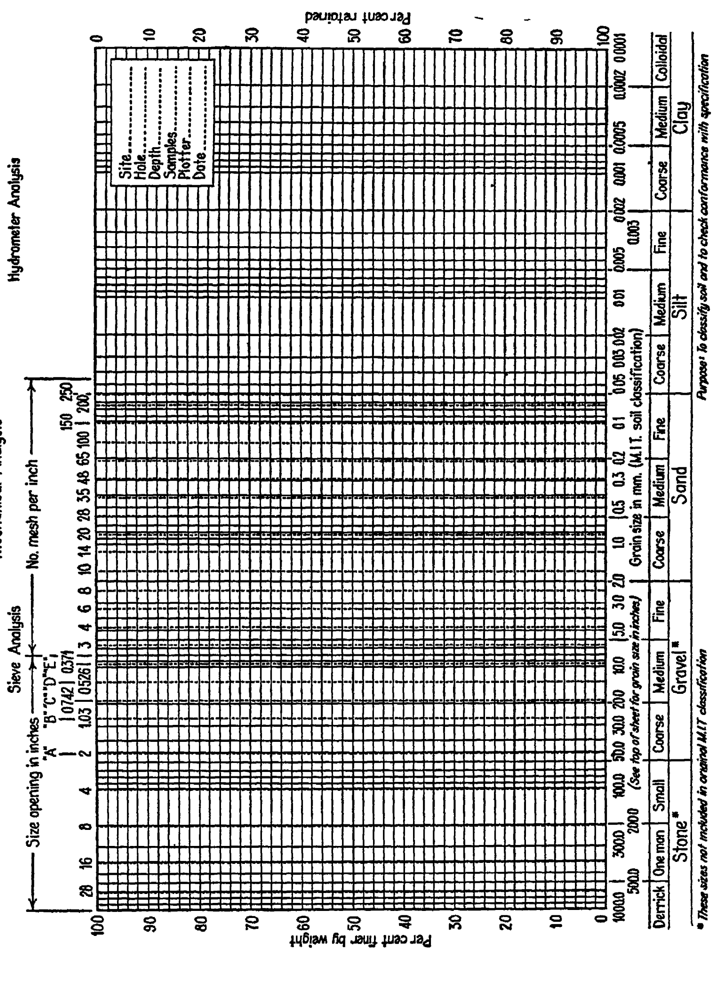
____________________

____________________

____________________

____________________

*Note.* Mark samples with name of base, name of structure, hole number, sample number, depth, and material.




*From the Haller Engineering Associates, Inc.*

## FIELD TESTING

### Specific Gravity and Surface Moisture

Use fruit jar (see Fig. 51) and 2-kilo. (5-lb.) balance accurate to $\frac{1}{10}$ gram.

**Specific Gravity.** Weigh jar full of water. Empty jar, place therein 700 grams surface-dry sample. Fill jar with water and weigh. Determine specific gravity from nomograph. See Fig. 51.

**Surface Moisture.** Same procedure except 700-gram sample is moist aggregate to be tested.

*Precautions.* Roll submerged sample to remove air. Jar must be dry outside when weighed. Use eye-dropper to insure completely filling with water. Remove foam.

**Surface Moisture, Heat Method.** Heat a weighed sample at 212° F., in open pan until surface water disappears (3 to 10 minutes). Weigh again. The difference between the original and the final weight is calculated as per cent of surface moisture.

**Total Moisture Content.** Heat weighed sample in open pan above 212° F. for 30 minutes or to constant weight. The difference between the original and the final weights is calculated as per cent of total moisture.

TABLE 36. APPROXIMATE SURFACE MOISTURE

(Use only when testing is impracticable)

| Condition of Aggregate | Per Cent by Weight |
|---|---|
| Very wet sand | 6 to 8 |
| Average stock pile sand, drained | 3½ to 4 |
| Moist sand | 2 |
| Moist gravel or crushed rock | 2 |

### Tests of Gradation. Sieve Analysis, A.S.T.M. C-136

Quarter sample until sufficient material remains to give a dry sample as follows: sand under No. 10, 100 grams (0.2 lb.); sand under No. 4, 500 grams (1.1 lb.); coarse sand, 1000 grams (2.2 lb.); coarse aggregate under 1 in. maximum, 10 kg. (22 lb.); 2 in. maximum, 20 kg. (44 lb.); 3 in. maximum, 30 kg. (66 lb.). Use square- or round-aperture sieves as specified and of the sizes specified. If not specified, use square-mesh sieves as follows: bituminous aggregates, Nos. 200, 80, 40, 10, 4, ⅜ in., ½ in., ¾ in., 1 in., 1¼ in., 1½ in.; concrete aggregates, Nos. 100, 50, 30, 16, 8, 4, ⅜ in., ¾ in., 1½ in., 3 in. Use 8-in.-diameter sieves for samples of 5 kg. (11 lb.) or less and 16-in.-diameter sieves for larger samples. Use

balance or scale sensitive to 0.1% of sample weight. Set sieves in sequence with smallest size on bottom. Weighed sample is set on top sieve, and sieves are vibrated by lateral and vertical motion with jarring action. Weigh amount retained on each sieve and in pan, and compute percentage.

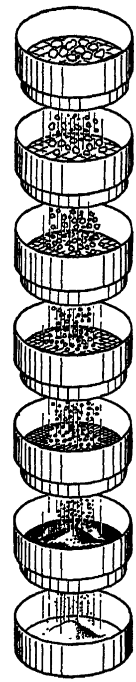


FIG. 63. Sieves.

### Fineness Modulus

Add cumulative per cent retained on each of U. S. Standard Sieves listed above for concrete. Divide sum by 100; result equals fineness modulus.

### Material Finer than No. 200 Sieve—Silt and Clay in Fine Aggregate, A.S.T.M. C-117

Use two sieves, No. 200 and No. 16, and a vessel large enough to contain the sample covered with water, and permit agitation. Select a moist sample large enough to weigh 500 grams (1.1 lb.) when dry. The sample after being dried to constant weight is placed in the container and covered with water. The contents of the container are agitated vigorously and the wash water is poured over the nested sieves, the No. 16 being on top. The operation is repeated until the wash water is clear. The washed aggregate is dried to constant weight and weighed to nearest 0.02%.

% of minus No. 200 material

$$= \frac{\text{original dry weight} - \text{dry weight after washing}}{\text{original dry weight}} \times 100$$

### Approximate Amount of Silt and Clay

Place fine aggregate in a pint bottle to a height of 4 in.; then add water until the bottle is nearly full. Shake thoroughly, and allow to settle for 1 hr. or until the water is clear. Silt and clay will settle on top. The thickness of this layer should not be over ⅛ in. Alternative: Place 5 oz. of sand in 12-oz. graduated bottle and add water until the mixture equals 10 oz. after shaking. Allow to settle as above. If silt and clay content is more than 3% or as specified, sand should be washed or additional laboratory tests made.

### Organic Impurities in Fine Aggregate (Colorimetric Test), A.S.T.M. C-40

Fill a 12-oz. graduated prescription bottle to the 4½-oz. mark, with the sample to be tested. Add a 3% solution of caustic soda, known as sodium

hydroxide, until the volume of sand and solution after shaking reaches the 7-oz. mark. Let the bottle stand for 24 hr., then observe the color of the liquid above the sand. If colorless or light amber color, the sand may be considered satisfactory. If it is light brown or darker, the sand should be sent to laboratory for additional tests.

### Unit Weight of Aggregate, Dry Rodded Method, A.S.T.M. C-29

Use a calibrated bucket of minimum No. 11 gage metal, a ⅝-in. by 24-in. bullet-pointed tamping rod, and a scale accurate to 0.5%. The capacity of the bucket in cubic feet should be as follows: ½-in. maximum aggregate size use ⅒ cu. ft.; 2-in. maximum aggregate size use ⅓ or ½ cu. ft.; 4-in. maximum aggregate size use 1 cu. ft. Aggregate should be room dry and thoroughly mixed. Fill the measure in 3 equal layers, rodding each layer 25 times. Strike off top layer and determine net weight. Calculate weight per cubic foot (unit weight). *Note.* In rodding use only enough force to penetrate the layer being rodded. The rod should not strike the bottom of the bucket.

### Voids in Aggregate, A.S.T.M. C-30

$$\%\text{ of voids} = \frac{(\text{specific gravity of aggregate} \times 62.4) - \text{weight}}{(\text{specific gravity of aggregate} \times 62.4)} \times 100$$

where weight equals the weight in pounds per cubic foot of the aggregate as determined by the unit weight test above (A.S.T.M. C-29). Specific gravity is determined by nomograph, p. 116, or by laboratory.

### Absorption of Aggregates

The following table may be used as a guide for the field where A.S.T.M. Tests C-127 and C-128 are not practicable.

TABLE 37. APPROXIMATE ABSORPTION OF WATER BY AGGREGATES

| | Per Cent by Weight |
|---|---|
| Average sand | 1.0 |
| Calcareous pebbles and crushed limestone | 1.0 |
| Trap rock and granite | 0.5 |
| Porous sandstone | 7.0 |

TUTTLE, SEELYE, PLACE AND RAYMOND
ARCHITECT-ENGINEER
FORT DIX NEW JERSEY

Contract No. ______ Date of test ______
Contractor ______ Type construction ______
Source of material ______ Plant ______
Sampled at ______ Used at station or building ______
Specification ______ Material ______

REPORT ON AGGREGATES—SIEVE ANALYSIS

| Screen or Sieve Size | Round or Square Shape | Weight Retained | Weight Passing | % Passing | % Spec. Reqmts. *Min. Max.* |
|---|---|---|---|---|---|
| 3″ | | | | | |
| 2½″ | | | | | |
| 2¼″ | | | | | |
| 2″ | | | | | |
| 1½″ | | | | | |
| 1¼″ | | | | | |
| 1″ | | | | | |
| ¾″ | | | | | |
| ½″ | | | | | |
| ⅜″ | | | | | |
| ¼″ | | | | | |
| No. 4 | | | | | |
| No. 8 | | | | | |
| No. 16 | | | | | |
| No. 30 | | | | | |
| No. 50 | | | | | |
| No. 100 | | | | | |
| No. 200 | | | | | |
| Pan | | | | | |

WEIGHTS OF SAMPLE

Total weight ______

Dry weight ______

Difference ______ % moisture

After washing ______

% gravel (over ¼″) ______

Clay, etc. ______ % ______

Material retained on ______

______ Sieve ______ ______ %

Fineness modulus = sum cumulative % retained on each of Nos. 100, 50, 30, 16, 8, and 4, ⅜-in., ¾-in., 1½-in., and 3-in. sizes ÷ 100 =

Remarks:

Remarks:

Approved Disapproved

______
Engineer

Tested by:

______
Inspector

# CHECK LIST FOR INSPECTORS

## GRADING

### Inspectors' Equipment

Complete set of approved plans and specifications.
Surveying instruments if required.
100-ft. tape and 6-ft. rule.
Line level and line.
Equipment for sampling and testing soils as required.

### Procedure in Inspection

**Preparation of Site.** Check against specifications for:
Stripping.
Storage of topsoil.
Removal of obstructions.
Clearing and grubbing.
Protection of trees.
Removal of peat, muck, humus, sod.
Removal or resetting of poles.
Resetting or installation of culverts.
Drains, sewers, water pipes, utilities.
Cavities and trenches to be backfilled and tamped.
Stake grades and slopes.
Cross-section borrow pits.
Cross-section rock as exposed before excavating.

**Selection of Material.** Follow specifications in selecting material such as placing granular material under paved areas.

Broken rocks on slopes and in marshy foundations.

Wasting peat, muck, frozen clods, organic matter.

**Soil Compaction.** Check specification requirements such as:

Weight of equipment and number of passes. Eight to twelve passes with sheepsfoot roller are customary. Three-wheel roller, 8 to 12 tons for final rolling of each layer and on the subgrade beneath base course. Caterpillar tractors may be used for granular soils when sheepsfoot or three-wheel rollers are not effective.

Thicknesses of layers rolled (usually 4 in. to 12 in.).

Harrows, rotary tillers, reduction of moisture and soil mixture.

Provision of water distribution in dry weather.

Provision of uniform travel for construction equipment.

Do not permit end dumping over face of high fills.

Stable slopes may be obtained by filling beyond final grade and subsequently excavating to that grade.

Protection of pipes from injury by equipment during construction.

# BITUMINOUS PAVING

## FIELD SAMPLING

| Material and Method | When Sampled | Size of Sample | Instructions |
|---|---|---|---|
| Asphalt, cement, crude asphalt, refined asphalt, bituminous materials, A.S.T.M.' D-140 | From each source in advance of work and from each carrier as delivered | 1 qt. min. Asphalt emulsion or cut-back 2 qt. min. | Draw sample from top, bottom, and middle of tank by lowering bottle or can fitted with a stopper or lid lifted by attached wire, or sample may be taken from drain cock after initial draining. Solid or semi-solid asphalt sampled with clean hatchet or putty knife. Place liquids in small-mouth cans with cork-lined screw top. Place semi-solid material in friction lid cans. Ship crated or boxed. Mark cans. |
| Asphalt, A.S.T.M. D-290 | Daily, for penetration test | 3 oz. min. | Draw sample into can from valve over asphalt bucket on plant. Mix and pour into tin or glass container. |
| Asphalt sand, screenings, crushed stone and gravel, mineral fillers, A.S.T.M. D-75 | Each source<br>First shipment and if any change for laboratory tests<br>Daily from piles or bins for plant tests | Fine aggregates 5 lb. min.; coarse aggregates 20 lb. | Quarter samples to size required. Sample from pits by channeling open face or from test hole. Sample from stock piles in various places avoiding base of pile. From cars, sample from top, middle, and bottom. Ship in strong, tight bags or boxes. At plant, sample separate sizes and composite mixture for daily sieve tests. |
| Heated and dried aggregates, A.S.T.M. D-290 | Daily from bins | Fine, 5 lb.; coarse, 20 lb. | Pass shovel or pan quickly through stream of hot material as it flows from bin for daily sieve tests. |
| Bituminous mixtures (sheet asphalt, bituminous concrete, road mix, sand asphalt, plant mixes), A.A.S.H.O.T-41, A.S.T.M. D-290 | Daily, or as specified or directed | Sheet asphalt, 1 lb. min.; bituminous concrete, 5 lb. min.; cold mixes, 15 lb. min.; compressed mixture, 6 to 12 in. sq. by full depth | At plant, take small portions from a number of batches during day, mix, and quarter to size. At paving site, compose sample from top, bottom, front, and back of load. Road mixes, shovel from course full depth, mix, and quarter. Ship samples in clean, tight box, carton, or friction lid can. Compressed samples, select location where mix is representative, before seal coat and after final rolling. Cut exact square to full depth of course. |

MARKING SAMPLES—ALL MATERIALS

**General.** Same as for concrete field sampling, p. 11.

**Bituminous Material.** Railroad car number, refinery, type, grade, proposed use.

**Aggregates.** Kind, source, where sampled, separated size or combined mixture.

**Bituminous Mixtures.** Type, plant, date, specified mix, station or location placed.

## FIELD OR PLANT TESTS

*May be used when full-scale laboratory tests are not practicable*

**Penetration of Asphalt (A.S.T.M. D-5)** is the distance, measured in units of 1/10 mm., that a standard blunt-point needle will penetrate a sample of asphalt at 77° F. when the needle is loaded with 100 grams applied for 5 seconds. Sample selected per p. 139, melted, stirred, and poured into container, 2.17 in. diameter by 1.38 in. Place in water for 1 hour at 77° F. to a depth of 4 in. and 2 in. off bottom of vessel. Sample is penetrated in at least 3 places, and average penetration is reported.

*Notes.* Sample must be maintained at 77° F. during the test by placing in a transfer dish filled with water and by returning the sample to the water bath after each test. The needle must be wiped after each test. Metal "ointment box" of above dimensions may be obtained at drug store. The inspector should have orders as to action to take if penetration is not as specified.

NORMAL PENETRATION LIMITS

(77° F., 100 g., 5 sec.)

| | | |
|---|---|---|
| 25–30 | 50–60 | 85–100 |
| 30–40 | 60–70 | 100–120 |
| 40–50 | 70–85 | 120–150 |
| | | 150–200 |

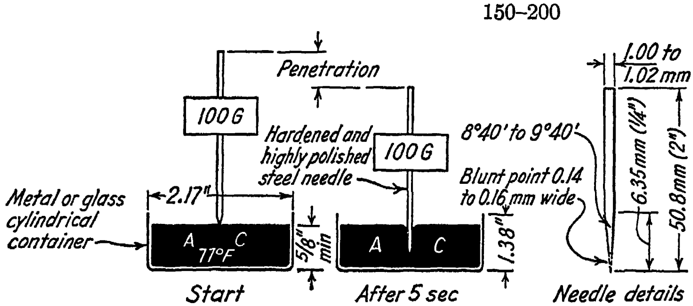



FIG. 64. Penetration test.

**Pat Test of Sheet Asphalt.** Select small sample of hot mix and note the temperature. Place at once upon a sheet of unglazed manila paper, resting upon a flat board. Fold the paper over the sample and press heavily with the flat of a wood paddle 6 in. long by 4 in. wide. Strike the paper a sharp blow with the paddle, open the paper, and remove the sample. If the stain is medium dark, bitumen content is about right. If it is very dark or sloppy, bitumen is excessive. If it is light and dry, bitumen is insufficient. If only the imprint of single sand grains appears, the amount of filler is deficient. If the space between sand grains is filled in, aggregate grading is good.

**Percentage of Bitumen and Mechanical Analysis of Mixtures.** The following method is for routine control where A.A.S.H.O. Tests T-58 and T-30 are not practicable. Dissolve and wash all the bitumen from a weighed sample of the mix with carbon tetrachloride, gasoline, or other solvent such as benzol, xylene, or chloroform, and weigh the recovered aggregate.

% of bitumen

$$= \frac{\text{weight of original sample} - \text{weight of recovered aggregate}}{\text{weight of original sample}} \times 100$$

*Note.* Wash aggregate clean. Avoid loss of any aggregate. If the percentage of bitumen varies from that specified, check the plant scales and the weighing operation. For sieve analysis of dried recovered aggregate (A.S.T.M. C-136 and C-117), see pp. 134 and 135, Aggregate Field Testing.

**Field Density of Compressed Mixture.** Immerse the weighed sample in hot paraffin, remove, cool, and weigh again. Weight gain is weight of paraffin. Volume of paraffin coat is calculated using 55 lb. per cu. ft. as weight of paraffin. Weigh the coated sample in water, record weight, and calculate the volume of the sample or measure the volume of the displaced water by an overflow device (weight water = 62.4 lb. per cu. ft.). Deduct the volume of the paraffin coat. Field density (lb. per cu. ft.) = net weight of sample in pounds ÷ volume of sample in cubic feet. The percentage of compaction = field density ÷ theoretical maximum density (from laboratory).

$$\% \text{ of voids} = \frac{\text{maximum density} - \text{field density}}{\text{maximum density}} \times 100$$

*Note.* Compaction to 94–96% of maximum density is usually specified.

## CHECK LIST FOR INSPECTORS

### BITUMINOUS PAVING—GENERAL

**Inspectors' Equipment**

Complete set of latest approved plans and specifications.

Penetrometer with extra needles and 3-oz. tins (optional; needed only when asphalt penetration is checked on job).

Supply of report forms, sample tags, cartons, cans, and sacks for shipping samples.

Metal dipper, pans, shovels, pails, etc., for sampling.

Armored thermometers of specified temperature range for both plant and field.

Set of screens or sieves of specified aggregate sizes.

Wire brush for cleaning sieves.

1 balance of 500-gram capacity.

1 scale or balance of 10- to 25-lb. capacity.

Supply of carbon tetrachloride or other solvent such as benzol, carbon disulfide, chloroform, or gasoline.

Putty knife for checking pavement depth.

6-ft. folding rule and 50-ft. steel tape.

10-ft. straightedge, 3-ft. straightedge, and template cut to required crown.

Grade line and string level.

Field books, pencils, keel or crayon.

Fruit jar, Chapman flask, or hot plate and pan for moisture content (not necessary for mixes with hot, dry aggregates).

## Procedure in Inspection

### Bituminous Treatments

**Prime Coat.** Applied to receptive surfaces; should soak in.

Subgrade or Base. Compacted to specified density; should not shove, creep, or weave under a moving road roller.

Width, elevation, and cross section.

Condition to receive prime; excess loose material removed but surface not so tightly bound as to be impervious; slightly moist surface better for cutbacks and tars than dry and dusty; surface may be quite damp for asphalt emulsions.

Application. Bituminous material tested, approved, and of specified type.

Distributor truck calibrated and volume of material in load determined.

Distance each load should cover, at the width spread and at the gallonage per square yard specified, measured off and marked conspicuously. Amount of bitumen used is usually 0.20 to 0.45 gal. per sq. yd. for tight surfaces and 0.4 to 0.6 for open surfaces.

Distributor checked for specified requirements, usually: mechanical circulator, dual tires, pressure gage, range of application rates, positive shut-off, thermometer, spray bar width, measuring stick, tachometer, application pressure, wheel load or tire pressure, clean apertures or jets, load calibration and capacity.

Specified temperature of application adhered to.

Net gallonage computed by applying temperature conversion factor to gallonage measured at application temperature, see p. 158.

Provision to prevent overlap at beginning and end of application strip; usually building paper is laid down to insure a clear-cut joint.

Cover Material. May or may not be specified. If not specified, a light

cover in spots may be necessary to prevent migration of bitumen on steep grades and banked curves.

If specified, check following: gradation, type, moisture content, rate and uniformity of application, dragging, rolling, brooming and sweeping.

Curing Period. As specified, should elapse before subsequent applications or pavement courses.

**Tack Coat.** Usually applied to hard, dense impervious surfaces, without soaking in.

Surface. Cleaned or swept, dry but not dusty, patched, brought to line, grade and cross section as specified.

Application. Same as for prime coat except for following precautions:

As application is very light (0.08 to 0.15 gal. per sq. yd.) distributor must travel at very high speed; tachometer is a necessity.

All distributor bar apertures or jets must be open and functioning.

Uniformity can be obtained by use of burlap drag behind distributor.

Great care must be exercised to prevent overlapping at sides and ends of strips; resulting fat spots will seriously affect pavement.

Surface must be kept tacky or sticky till pavement is laid, not allowed to be covered with dust or dirt; traffic must be kept off.

**Seal Coat.** Surface. Prepared as per specifications.

Application. Same as for prime coat with same precautions as for tack coat except bitumen is usually immediately covered with aggregate. Leave an 8-in. strip of bitumen uncovered for lapping adjacent strips.

Cover Material. May or may not be specified. If specified, check type, gradation, moisture content, rate and uniformity of application.

Applied at once after bitumen is spread so particles can be embedded. Material should be spread out ahead in piles or windrows or spreader trucks should be on job before bitumen is applied.

Specified method of uniformly distributing cover material followed.

Rolling, if specified, began at once and continued until aggregate is embedded. Excessive rolling, causing crushing of particles, avoided.

Broom or wire mesh dragging carried on simultaneously with rolling unless otherwise specified.

Excess cover material swept off after rolling if specified.

Back spotting of bleeding areas with cover material for several days.

**Mix-in-Place (Road Mix)**

Subgrade or Base. Compacted to specified requirements and shaped to correct width, grade and cross section.

Prime Coat. May or may not be specified. Same as for bituminous treatments.

Aggregates for Mix. Source approved and laboratory testing verified.

Gradation checked before use and continuously during operations.

Aggregate may be bank run or artificially mixed as specified; in either

case the aggregate, before mixing with bitumen, should conform to specified gradation.

Continuous check on any special requirements such as liquid limit, plasticity index, percentage of silt and clay, either by sending samples to laboratory or by field testing as directed by superiors.

Preparation of Aggregate. Loose aggregate spread flat or in windrows in such volume and to such depth as to produce specified thickness when compacted.

Coarse or fine material mixed into aggregates to produce specified gradation if necessary.

Mixed aggregate brought to specified moisture content by pulverizing and aeration if wet or by sprinkling if dry. If not specified otherwise, usually maximum 2% moisture for cutback asphalts and tars, and 4 to 5% moisture for emulsions. Sprinkling necessary only when aggregate is very dry and dusty.

As contractor will demand quick moisture readings, use of fruit jar pycnometer is recommended; see p. 134.

Application of Bituminous Material. (*a*) By Set Quantity per Square Yard. Same as for bituminous treatments, prime coat. Follow job specification for increments and sequence of application. If not specified, best practice is to apply in increments of 0.5 to 0.6 gal. per sq. yd. with partial mixing between increments. For dense graded mixes, 0.5 to 0.6 gal. per sq. yd. per inch of depth of finished mix should suffice.

(*b*) Quantity Varied per Aggregate Gradation. Inspector must make continual screen analysis and compute required quantity of bitumen by formula or method as specified or directed. Screen analysis made either at pit, plant, or on the site, preferably on the site. Bitumen usually 4 to 7% by weight.

Mixing. (*a*) By Blade Graders. Graders to cut clear down to base (but not to cut into or tear up the base) and make complete turnover. Mixture to roll over in front of grader blade. Mixing to begin at once behind bituminous application to prevent migration of bitumen. Graders to manipulate mixture back and forth across entire width of road or strip being placed. Mix in as long strips as possible keeping turnarounds to minimum. Mixing to continue until all aggregate particles are coated; usually 12 to 15 complete turnovers are necessary.

Areas deficient in bitumen, i.e., dry, brownish color, powdery, no cohesion, large particles uncoated, should receive additional bitumen and remixing.

Areas with excess bitumen, i.e., greasy, fat, sloppy, unstable, free bitumen in evidence, corrected by adding more aggregate and remixing.

(*b*) By Rotary Tillers (Pulvi-Mixers, Roto-Tillers, etc.). Same general procedure as for blade graders except:

Aggregate is usually spread flat and mixed flat.

Aggregate is not manipulated back and forth.

Bitumen applied in 0.4 to 0.6 gal. per sq. yd. increments with partial mixing between applications is best practice.

Watch for balling up of aggregate, i.e., lumps of uncoated aggregates.

If road or area is wide enough, transverse, diagonal or figure-8 travel of the Rotary-Tiller is recommended.

Mixing continued till all aggregates are coated for full depth.

*Note.* Rotary tillers and blade graders are sometimes operated in combination. Blade grader throws up windrow directly in front of rotary tiller, which mixes and spreads out flat; 10 to 12 repetitions of this process will usually produce uniform mixture.

(*c*) By Travel Plant Methods. Check calibration of measuring devices on machine.

Control of moisture content of aggregates by constant checking.

Gradation of material in windrows; continual screen analysis.

Accurate windrowing of aggregates ahead of travel plant to produce required finished thickness and width of pavement.

Mixed material as it leaves plant to have all aggregates coated, well mixed, and uniform in gradation and bitumen content.

Bituminous material introduced within specified temperature range.

Mixture may be spread with blade graders or paving machine; follow job specifications.

Curing. As specified.

Rolling. Equipment and methods as specified, to continue until mix is compacted to specified density, is smooth, and shaped to specified cross section and elevations.

Seal Coat. Same as for Bituminous Treatments.

**Penetration Macadam**

Subgrade or Base. Compacted to specified requirements and shaped to correct width, grade, and cross section.

Aggregates. Coarse stone, choke stone, and chips tested and approved for gradation and quality before use.

Inspection of gradation primarily visual, but screen analysis should be made once a day.

Avoid an excess of stone under 1¼-in. size, dust, and screenings, which will form mats that bitumen cannot penetrate.

Placing Aggregates. May be spread by hand, spreader boxes, machines, or blade graders.

Avoid segregation of coarse and fine stone.

Spread in layers as specified; 3½ in. to 4 in. is about the maximum thickness one layer can be built.

Depressions removed by working coarse stone into low areas; do not fill depressions with fine stone.

Pockets or areas of fine stone or choked with dust removed and replaced with properly graded stone.

Surface true, "spotted" to grade and cross section and without areas of excess fine or coarse stone before rolling begins.

**Initial Rolling.** Begin at sides and progress to center, overlapping shoulder and each previous wheel mark.

Rolling to continue until all stone keyed together.

Depressions developing during rolling corrected.

Rolling not to continue if stones are being crushed. Check stone soundness; if okay, add keystone or use lighter roller. (Some emulsified asphalt specifications require keystone to be spread during initial rolling; check.)

Roll in as long strips as possible to avoid reversing roller.

Rollers to operate in straight, not wavy, lines, and reverse motion smoothly, not in jerks.

Bituminous Application. Do not begin until surface is dry (except for emulsions), not dusty or excessively choked, and uniformly compacted.

Application is same as for prime coat, Bituminous Treatments.

Choke Stone (applied after bituminous material). Spread uniformly, just sufficient to fill voids in stone.

Rolled and broom dragged simultaneously until surface is thoroughly consolidated and free from large voids.

In hot weather or with asphalt emulsions this rolling and brooming may be postponed until day following bituminous application.

Continue rolling and broom dragging until all roller creases and marks are removed and surface does not creep or shove under roller wheels. Additional small amounts of keystone may be added during this process.

*Note.* Follow job specifications for quantity of bitumen and increments of application. Practice varies from applying bitumen in one heavy application with one choking and rolling to applying bitumen in two or three increments with choking and rolling after each.

Seal Coat. Same as for seal coat, Bituminous Treatments.

Pay Items. Accurate record of all pay items in contract.

Gallons of bituminous material placed (corrected for temperature).

Tons, square yards, or cubic yards of aggregates or completed pavement as specified.

Extra applications of bitumen and aggregates.

## CHECK LIST FOR INSPECTORS

## PLANT-MIX BITUMINOUS PAVING

### Procedure in Inspection

**Plant Inspection**

**Tested and Approved Materials.** Bituminous material, aggregates, and fillers tested and approved before use.

Samples of aggregates, bitumen, and mixture shipped to laboratory at least once a week.

Daily screen analysis of aggregates and completed mixture.

**Storage and Handling of Materials.** Aggregates stock piled to avoid segregation and intermingling.

Mineral filler stored in dry place.

**Plant.** Plant equipment to meet specifications.

Weighing devices to work properly. Check scales with standard weights.

Tare weight of asphalt bucket checked twice daily. Tare weight is weight of empty bucket including residue and adhering bitumen.

Bucket kept clean or correction made for adhering bitumen.

Weigh box large enough to prevent spilling, with tight gates and in good condition.

No segregation or intermingling of aggregates before mixing.

Screens of specified size to completely separate various sizes required.

Asphalt thermometers checked for correct reading.

Weighing facilities for mineral fillers.

Correction of aggregate grading if variation occurs.

Scales for aggregate and bitumen set to produce specified mixture.

No change in basic mix proportions without approval from engineer.

**Mixing Operations.** Specified moisture content of aggregates adhered to for cold aggregate mixes.

All aggregates coated with bitumen and mix of uniform color and consistency.

Bitumen bucket completely emptied or drained.

Mixing time as specified and sufficient to coat aggregate thoroughly.

On sheet-asphalt jobs sand gradation checked hourly.

Weekly check of aggregate scales or more often if variation occurs.

Net weight of truck loads to equal total batch weights; check once a week.

Aggregates and bitumen heated to specified or approved temperatures; keep daily record.

Aggregates or bitumen never to be heated above the specified limits.

Mixture leaves plant at specified or approved temperature.

Proportions of mixture checked daily by dissolving the bitumen of a representative sample and making screen analysis of aggregates.

**Transporting Mixture.** All trucks covered with canvas or tarpaulin.

Trucks cleaned and sprayed with light oil or soap emulsion before mixture is placed therein; avoid excess.

Insulated truck bodies preferable if available.

No loads sent out if weather will hinder proper laying; cooperate with field inspector and contractor in this respect.

### Field Inspection

**Subgrade or Base.** Compacted and shaped according to plans and specifications.

Prime or tack coats, if specified, properly applied and curing time elapsed.

Holes and depressions repaired and rolled in advance of paving.

Base dry before mix is placed.

*Note.* Proper compaction and contour of base and subgrade are essential to a smooth and satisfactory pavement.

**Forms.** If specified, must be rigidly supported and accurately set to line and grade.

**Placing.** Paving machines and rollers inspected and approved before use for conformance with specified requirements.

Screeds on paver checked for crown ordinates. See p. 229 for crown offsets.

Screeds cleaned at noon and night shutdowns with fuel oil and scrapers.

Contact surfaces of paving equipment lightly oiled.

Avoid excessive hand raking behind paver. Paver should be so adjusted that only occasional touching behind will be necessary by hand.

Notify plant to shut down if rain begins. Loads in transit are customarily allowed to be placed if they are covered and temperature is sufficiently high.

Mixture delivered at proper temperature and not too rich or too lean.

*Note.* Excessive bitumen in mix will flush to surface during rolling and mix will be fat, greasy, and soupy. Deficient bitumen is indicated by cracking under roller, pushing into lumps, and dull, lusterless appearance. Either condition must be reported immediately to plant inspector.

Check temperature frequently by use of immersion armored thermometer of Weston type or equal.

An overheated or burnt-up batch will usually give off a cloud of acrid, white smoke when dumped.

If bitumen drains off or migrates to bottom of truck and aggregate on top is uncoated, the plant inspector should be notified immediately.

Check thickness of course as follows: (1) Compute number of square yards a load will cover, and make a mark on the base to which a load should spread. (2) After initial rolling make small hole with putty knife in mixture and check depth with rule. (3) Check square yards laid against tons hauled at noon and at end of day. For dense bituminous concrete mixes, the yield should be about 1 sq. yd. for 1 in. in depth for every 110 lb. of mix.

Mixture spread to a loose depth that will produce specified finished thickness; loose depth must be determined by experiment.

**Hand Spreading.** Each shovelful turned over as placed and load so dumped that entire batch is shoveled into place.

Workmen not to walk in loose mixture.

Avoid excessive raking that pulls coarse stone to surface.

Control depth with spreading blocks of correct height.

Shovels, rakes, and tampers kept hot and clean.

**Rolling.** Rollers of type and weight specified, and equipped with water spray and scrapers on wheels.

Begin rolling as soon after spreading as mixture will bear the roller without shoving or hair cracking.

When specified, check square yards rolled per hour per roller.

Begin rolling at sides and proceed toward center, overlapping one-half width of roller on successive passes.

If not specified otherwise, use tandem rollers for initial rolling and keep 3-wheel rollers off until mix is somewhat cooled.

Rollers to reverse motion smoothly, not in jerks.

Length of roller passes to be staggered.

Surface checked immediately after initial rolling with straightedge and template. This must be done before mix cools so corrections can be made. Tolerance usually ⅛ in. to ¼ in. in 10 ft. Try to correct surface before mix hardens to avoid unsightly skin patches later.

Rollers and trucks not to park on pavement while it is still plastic.

Excessive rolling avoided; it will cause crushing of aggregate and displacement of mix.

Rolling diagonally and at right angles very desirable if width of street or road is sufficient.

Rolling continued until all roller creases are removed and specified density is attained.

**Joints.** At shutdowns and end of day's work, transverse joints are formed by rolling over edge and then cutting back a vertical joint at full depth.

All cold joints painted with liquid bitumen and fresh mixture rolled firmly against the joint face.

**Seal Coat.** If specified, check gallons per square yard, temperature, and type of material.

**Final Inspection.** Depressions and bumps over specified tolerance corrected by concentrated rolling or skin patches.

Oil spots and fat spots cut out and refilled and tamped.

Disintegrated spots where mixture is raveling cut out to full depth with vertical faces and refilled with fresh mixture thoroughly tamped and rolled.

**Opening to Traffic.** Edges protected from traffic runover before opening pavement, usually after final rolling when mix has cooled off and hardened or from 4 to 12 hr. after placing.

**Pay Items.** Accurate record kept of all contract pay items, such as:

Tons, square yards, or cubic yards (as specified) of mixture laid.

Volume of embedded structures if deducted from unit price.

Gallons or square yards of any prime, tack, or seal coats applied.

Record of batches condemned or wasted.

Any other contract pay items.

## TABLE 38. USE OF BITUMINOUS MATERIALS

| Material | Road Tar (RT) Cutback Road Tar (RTCB) | | | | | | | | | | | | | | Road Oil, Slow Curing Asphaltic (SC) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commercial grade | RT-1 | RT-2 | RT-3 | RT-4 | RT-5 | RT-6 | RT-7 | RT-8 | RT-9 | RT-10 | RT-11 | RT-12 | RTCB-5 | RTCB-6 | SC-0 | SC-1 | SC-2 | SC-3 | SC-4 | SC-5 | SC-6 |
| Application temperature, °F | 60–125 | 60–125 | 80–150 | 80–150 | 80–150 | 80–150 | 150–225 | 150–225 | 150–225 | 175–250 | 175–250 | 175–250 | 60–120 | 60–120 | 50–120 | 125–175 | 120–225 | 160–250 | 175–275 | 225–350 | 300–400 |
| Penetration macadam, hot | | | | | | | | | | x* | x* | x | | | | | | | | | x |
| Penetration macadam, cold | | | | x | x | x | | | | | | | | | | | | | | | |
| Plant-mix, open-graded mixes | | | | | | | x* | x* | x* | x | x† | x† | | | | | | | | x | x |
| Mix-in-place, open graded (crushed stone) | | | | | x* | x* | x* | x† | x† | | | | x | x | | | | | | x† | |
| Plant-mix, dense-graded mixes | | | | | | | x | x | x | x | x | x | | | | | | x | x | x | x |
| Mix-in-place, dense-graded mixes (gravel mulch) | | | | x* | x | x | x† | x† | | | | | x | x | | | x | x | x† | | |
| Bituminous concrete | | | | | | | | | | x | x | x | | | | | | | | | |
| Surface treatment | | x | x | x | x | x | x | x | x | x | x | | x | x | | x | x | x | x | x | x |
| Seal coats (fog, flush, or sand cover) | | | | x | x | x | | | | | | | | | | | x | x | | | |
| Seal coats (carpet, stone, or armor coat) | | | | | x | x | x | x | x | x | x | | x | x | | | | | x | x | x |
| Tack coats | | | | x | x | x | x | x | x | x | | | | | | | | | | | |
| Prime coats (dense or tight bases) | x* | x | | | | | | | | | | | | | | x | x | | | | |
| Prime coats (porous or open bases) | | x* | x | x† | | | | | | | | | | | | | x | | | | |
| Soil stabilization | x | x | x | x | x | x | | | | | | | | | | | | | | | |
| Dust palliative | x | | | | | | | | | | | | | | x | x | x | | | | |
| Patching mixtures (cold patch) | | | | x* | x* | x | x† | x† | | | | | x* | x | | | x* | x† | x† | x† | |
| Sand tar | | | | | | | | | | | | | | | | | | | | | |
| plant mix | | | | | | | | x | x | x | | | | | | | | | | | |
| road mix | | | | | | x | x | x† | | | | | | | | | | | | | |
| Crack and joint filler | | | | | | | | | | x* | x | x | | x | | | | | | | |

* Cool weather work (spring and fall). † Hot weather work (summer).

*Note.* For both tars and road oils, the higher the number the more viscous the material. Thus an RT-1, RT-2, and SC-0 are non-viscous liquids at ordinary temperatures suited for soaking into a tightly bound base like clay-gravel. RT-4 to RT-7 and SC-2 to SC-4 will remain semi-liquid and are suited for mixing in place. RT-9 to RT-12 and SC-5 or SC-6 become solid or semi-solid at air temperatures and are suited for hot plant mixes, sealing, and macadam.

*References.* P. R. A., Koppers Co., Barrett Co., A.S.C.E., Barber-Greene Co.

## TABLE 38. USE OF BITUMINOUS MATERIALS, Continued

| Material | Medium Curing Cut-back Asphalt (MC) | | | | | | Rapid-curing Cutback Asphalt (RC) | | | | | | Asphalt Emulsion (AE) | | | | Asphalt Cement (AC) Penetration | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commercial grade | MC-0 | MC-1 | MC-2 | MC-3 | MC-4 | MC-5 | RC-0 | RC-1 | RC-2 | RC-3 | RC-4 | RC-5 | SS-1 & 2 | MS-1 | MS-2 & 3 | RS-1 | 25 to 45 | 45 to 70 | 70 to 85 | 85 to 150 | 150 to 200 |
| Application Temperature, °F. | 60 150 | 80 175 | 150 200 | 175 225 | 175 250 | 200 275 | 60 125 | 60 150 | 125 175 | 150 200 | 175 225 | 200 250 | 50 120 | 60 120 | 60 120 | 80 135 | 275 350 | 250 350 | 250 350 | 250 350 | 250 400 |
| Penetration macadam | | | | | | | | | | | | | | | | | | | | | |
| hot | | | | | | | | | | | x | x | | | | | | | x† | x | x* |
| cold | | | | | | | | | | | | | | | | x | | | | | |
| Plant-mix, open-graded | | | | | x | x | | | | x | x | x | | | x | | | | | | x |
| Mix-in-place, open-graded (crushed stone) | | | | x | x | | | | x | x | x | | | x | | | | | | | |
| Plant-mix, dense-graded | | | | x | x | x | | | | x | x | x | x | | x | | | | | x | x |
| Mix-in-place, dense-graded (mulch) | | | x | x | x† | | | | | | | | x | | | | | | | | |
| Bituminous (asphaltic) concrete | | | | | | | | | | | | | | | | | | x | x | x | x* |
| Sheet asphalt | | | | | | | | | | | | | | | | | | x | x | | |
| Sand asphalt plant-mix | | | x | x | | | | | x | x | x | | | | | | | | x | x | |
| Sand asphalt mix-in-place (road mix) | | | | x | | | | x | x | | | | | x | | | | | | | |
| Surface treatment | | x | x | x | x | x | | x | x | x | x | x | | x | | x | | | | x | x |
| Seal coats (fog, flush, or sand cover) | x | x | x | x | | | x | x | x | | | | | | | x | | | | | x |
| Seal coats (carpet, stone, or armor coat) | | | x | x | x | x | | | x | x | x | x | | x | | x | | | x | x | x |
| Tack coats | | | x | x | | | | x | x | x | x | | | | | x | | | | | x |
| Prime coats, dense or tight bases | x* | x† | | | | | | | | | | | x | | | | | | | | |
| Prime coats, open or porous bases | | x | x | | | | | | | | | | x | x | | x | | | | | |
| Soil stabilization | | | x | | | | | | x | | | | x | | | | | | | | |
| Dust palliative | x | x | | | | | x | | | | | | x | | | | | | | | |
| Patching mixtures (cold patch) | | | x | x | x | | | x | x | x | | | | | x | | | | | | |
| Joint filler, brick | | | | | | | | | | | | | | | | | x | | | | |
| Crack and joint filler | | | | | | | | | | | x | x | | | | | | x | x | x | |

* Cool weather work (spring and fall). † Hot weather work (summer).

*Note*: For cutback asphalts, the higher the number the more viscous the material. For asphalt cements, the higher the penetration number the softer the asphalt; thus for heavy traffic in hot weather a stiff grade such as 45 to 70 or 70 to 85 is used and for cool weather or light traffic softer grades are used. For asphalt emulsions: SS = slow setting; MS = medium setting; RS = rapid setting.

*References*, P.R.A., Asphalt Institute, A.S.C.E., Barber-Greene Co., Texas Co.

**TABLE 39. GALLONS ASPHALTIC MATERIALS REQUIRED AT VARIOUS RATES OF APPLICATION ***

GALLONS PER 100 LINEAR FEET

| Width, ft. | 9 | 12 | 15 | 16 | 20 |
|---|---|---|---|---|---|
| Gal. per Sq. Yd. | | | | | |
| 0.10 | 10. | 13.3 | 16.7 | 17.8 | 22.2 |
| 0.15 | 15. | 20.0 | 25.0 | 26.7 | 33.3 |
| 0.20 | 20. | 26.7 | 33.3 | 35.6 | 44.4 |
| 0.25 | 25. | 33.3 | 41.7 | 44.5 | 55.5 |
| 0.30 | 30. | 40.0 | 50.0 | 53.4 | 66.6 |
| 0.35 | 35. | 46.7 | 58.3 | 62.3 | 77.7 |
| 0.40 | 40. | 53.3 | 66.7 | 71.2 | 88.8 |
| 0.45 | 45. | 60.0 | 75.0 | 80.1 | 99.9 |
| 0.50 | 50. | 66.7 | 83.4 | 89.0 | 111.1 |
| 1.25 | 125. | 166.3 | 208.4 | 222.3 | 277.7 |
| 2.00 | 200. | 266.7 | 333.4 | 355.6 | 444.4 |

GALLONS PER MILE

| Width, ft. | 9 | 12 | 15 | 16 | 20 |
|---|---|---|---|---|---|
| Gal. per Sq. Yd. | | | | | |
| 0.10 | 530 | 700 | 880 | 940 | 1,170 |
| 0.15 | 790 | 1,050 | 1,320 | 1,410 | 1,760 |
| 0.20 | 1,050 | 1,410 | 1,760 | 1,880 | 2,350 |
| 0.25 | 1,320 | 1,760 | 2,200 | 2,350 | 2,930 |
| 0.30 | 1,580 | 2,110 | 2,640 | 2,820 | 3,520 |
| 0.35 | 1,840 | 2,460 | 3,080 | 3,290 | 4,110 |
| 0.40 | 2,110 | 2,820 | 3,520 | 3,750 | 4,690 |
| 0.45 | 2,330 | 3,170 | 3,960 | 4,220 | 5,280 |
| 0.50 | 2,640 | 3,520 | 4,400 | 4,690 | 5,870 |
| 1.25 | 6,600 | 8,800 | 11,000 | 11,730 | 14,670 |
| 2.00 | 10,560 | 14,080 | 17,600 | 18,770 | 23,470 |

* *From Pocket Reference for Highway Engineers, Asphalt Institute.*

**TABLE 40. TONS MINERAL AGGREGATE REQUIRED AT VARIOUS RATES OF APPLICATION ***

TONS PER 100 LINEAR FEET

| Width, ft. | 9 | 12 | 15 | 16 | 20 |
|---|---|---|---|---|---|
| Lb. per Sq. Yd. | | | | | |
| 10 | .5 | .67 | .84 | .89 | 1.11 |
| 15 | .75 | 1.0 | 1.25 | 1.33 | 1.67 |
| 20 | 1.0 | 1.33 | 1.67 | 1.77 | 2.22 |
| 25 | 1.25 | 1.67 | 2.08 | 2.22 | 2.78 |
| 30 | 1.5 | 2.0 | 2.50 | 2.67 | 3.33 |
| 35 | 1.75 | 2.33 | 2.92 | 3.11 | 3.89 |
| 40 | 2.0 | 2.67 | 3.33 | 3.56 | 4.44 |
| 45 | 2.25 | 3.0 | 3.75 | 4.0 | 5.0 |
| 50 | 2.5 | 3.33 | 4.16 | 4.44 | 5.55 |

TONS PER MILE

| Width, ft. | 9 | 12 | 15 | 16 | 20 |
|---|---|---|---|---|---|
| Lb. per Sq. Yd. | | | | | |
| 10 | 27 | 35 | 44 | 47 | 59 |
| 15 | 40 | 53 | 66 | 71 | 88 |
| 20 | 53 | 71 | 88 | 94 | 117 |
| 25 | 66 | 88 | 110 | 118 | 147 |
| 30 | 80 | 106 | 133 | 141 | 176 |
| 35 | 93 | 124 | 155 | 165 | 205 |
| 40 | 106 | 141 | 177 | 188 | 234 |
| 45 | 119 | 159 | 199 | 212 | 264 |
| 50 | 133 | 177 | 221 | 236 | 293 |

* *From Pocket Reference for Highway Engineers, Asphalt Institute.*

## TABLE 41. CUBIC YARDS OF AGGREGATE REQUIRED PER 100 LINEAR FEET AND PER MILE FOR VARIOUS LOOSE DEPTHS ON ROADS OF VARIOUS WIDTHS *

| Width of Road | Area | | Cubic Yards for Various Loose Depths | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Per | Sq. Yards | 1″ | 1½″ | 2″ | 2½″ | 3″ | 3½″ | 4″ | 5″ | 6″ |
| 6′ | 100′ | 66.6 | 1.9 | 2.8 | 3.7 | 4.6 | 5.6 | 6.5 | 7.4 | 9.3 | 11.1 |
| | Mile | 3520.0 | 97.8 | 146.7 | 195.6 | 244.4 | 293.3 | 342.2 | 391.1 | 488.9 | 586.7 |
| 7′ | 100′ | 77.7 | 2.2 | 3.2 | 4.3 | 5.4 | 6.5 | 7.6 | 8.6 | 10.8 | 13.0 |
| | Mile | 4106.6 | 114.1 | 171.1 | 228.1 | 285.2 | 342.2 | 399.3 | 456.3 | 570.4 | 684.4 |
| 8′ | 100′ | 88.8 | 2.5 | 3.7 | 4.9 | 6.2 | 7.4 | 8.6 | 9.9 | 12.3 | 14.8 |
| | Mile | 4693.3 | 130.4 | 195.6 | 260.7 | 325.9 | 391.1 | 456.3 | 521.5 | 651.9 | 782.2 |
| 9′ | 100′ | 100.0 | 2.8 | 4.2 | 5.6 | 6.9 | 8.3 | 9.7 | 11.1 | 13.9 | 16.7 |
| | Mile | 5280.0 | 146.7 | 220.0 | 293.3 | 366.7 | 440.0 | 513.3 | 586.7 | 733.3 | 880.0 |
| 10′ | 100′ | 111.1 | 3.1 | 4.6 | 6.2 | 7.7 | 9.3 | 10.8 | 12.3 | 15.4 | 18.5 |
| | Mile | 5866.6 | 163.0 | 244.4 | 325.9 | 407.4 | 488.9 | 570.4 | 651.9 | 814.8 | 977.8 |
| 12′ | 100′ | 133.3 | 3.7 | 5.6 | 7.4 | 9.3 | 11.1 | 13.0 | 14.8 | 18.5 | 22.2 |
| | Mile | 7040.0 | 195.6 | 293.3 | 391.1 | 488.9 | 586.7 | 684.4 | 782.2 | 977.8 | 1173.3 |
| 14′ | 100′ | 155.5 | 4.3 | 6.5 | 8.6 | 10.8 | 13.0 | 15.1 | 17.3 | 21.6 | 25.9 |
| | Mile | 8213.3 | 228.1 | 342.2 | 456.3 | 570.4 | 684.4 | 798.5 | 912.6 | 1140.7 | 1368.9 |
| 16′ | 100′ | 177.7 | 4.9 | 7.4 | 9.9 | 12.3 | 14.8 | 17.3 | 19.8 | 24.7 | 29.6 |
| | Mile | 9386.6 | 260.7 | 391.1 | 521.5 | 651.9 | 782.2 | 912.6 | 1043.0 | 1303.7 | 1564.4 |
| 18′ | 100′ | 200.0 | 5.6 | 8.3 | 11.1 | 13.9 | 16.7 | 19.4 | 22.2 | 27.8 | 33.3 |
| | Mile | 10560.0 | 293.3 | 440.0 | 586.7 | 733.3 | 880.0 | 1026.7 | 1173.3 | 1466.7 | 1760.0 |
| 20′ | 100′ | 222.2 | 6.2 | 9.3 | 12.3 | 15.4 | 18.5 | 21.6 | 24.7 | 30.9 | 37.0 |
| | Mile | 11733.3 | 325.9 | 488.9 | 651.9 | 814.8 | 977.8 | 1140.7 | 1303.7 | 1629.6 | 1955.6 |
| 21′ | 100′ | 233.3 | 6.5 | 9.7 | 13.0 | 16.2 | 19.4 | 22.7 | 25.9 | 32.4 | 38.9 |
| | Mile | 12320.0 | 342.2 | 513.3 | 684.4 | 855.6 | 1026.7 | 1197.8 | 1368.9 | 1711.1 | 2053.3 |
| 23′ | 100′ | 255.5 | 7.1 | 10.6 | 14.2 | 17.7 | 21.3 | 24.8 | 28.4 | 35.5 | 42.6 |
| | Mile | 13493.3 | 374.8 | 562.2 | 749.6 | 937.0 | 1124.4 | 1311.9 | 1499.3 | 1874.1 | 2248.9 |
| 24′ | 100′ | 266.6 | 7.4 | 11.1 | 14.8 | 18.5 | 22.2 | 25.9 | 29.6 | 37.0 | 44.4 |
| | Mile | 14080.0 | 391.1 | 586.7 | 782.2 | 977.8 | 1173.3 | 1368.9 | 1564.4 | 1955.6 | 2346.7 |

Rolling compacts crushed aggregate base course approximately 20% and wearing course approximately 25%.
Ordinary bank gravel compacts approximately 33⅓%.
For road 5′ wide take half of 10′ quantity.
For road 22′ wide add quantities for 10′ and 12′ widths.
For road 26′ wide add quantities for 20′ and 6′ widths.
For road 28′ wide take twice quantity for 14′ width.
For road 30′ wide take three times quantity for 10′ width.

* *From Tarmac Handbook, Koppers Co.*

### TABLE 42. AREAS OF PAVEMENT SURFACES *

| Width in Feet | Square Feet per Mile | Square Yards per Mile | Square Yards per Linear Foot |
|---|---|---|---|
| 1 | 5,280 | 587 | 0.1111 |
| 8 | 42,240 | 4,693 | 0.8888 |
| 9 | 47,520 | 5,280 | 1.0000 |
| 10 | 52,800 | 5,867 | 1.1111 |
| 11 | 58,080 | 6,453 | 1.2222 |
| 12 | 63,360 | 7,040 | 1.3333 |
| 15 | 79,200 | 8,800 | 1.6667 |
| 16 | 84,480 | 9,387 | 1.7778 |
| 18 | 95,040 | 10,560 | 2.0000 |
| 20 | 105,600 | 11,733 | 2.2222 |
| 22 | 116,160 | 12,906 | 2.4444 |
| 24 | 126,720 | 14,080 | 2.6667 |
| 26 | 137,280 | 15,253 | 2.8888 |
| 28 | 147,840 | 16,426 | 3.1110 |
| 30 | 158,400 | 17,600 | 3.3333 |
| 32 | 168,960 | 18,773 | 3.5555 |
| 36 | 190,080 | 21,120 | 4.0000 |
| 40 | 211,200 | 23,467 | 4.4444 |
| 50 | 264,000 | 29,333 | 5.5556 |

* *From Bitumuls Handbook, American Bitumuls Co.*

### TABLE 43. LINEAR FEET COVERED BY 1 TON OF AGGREGATE AT VARIOUS RATES OF APPLICATION *

| Width, ft. | 9 | 12 | 15 | 16 | 20 |
|---|---|---|---|---|---|
| Lb. per Sq. Yd. | | | | | |
| 10 | 200 | 150 | 120 | 113 | 90 |
| 15 | 133 | 100 | 80 | 75 | 60 |
| 20 | 100 | 75 | 60 | 56 | 45 |
| 25 | 80 | 60 | 48 | 45 | 36 |
| 30 | 67 | 50 | 40 | 38 | 30 |
| 35 | 57 | 43 | 34 | 32 | 26 |
| 40 | 50 | 38 | 30 | 28 | 23 |
| 45 | 44 | 33 | 27 | 25 | 20 |
| 50 | 40 | 30 | 24 | 23 | 18 |

* *From Pocket Reference for Highway Engineers, Asphalt Institute.*

## TABLE 44. WEIGHT AND VOLUME RELATIONS MINERAL AGGREGATES *

### Broken Stone

*Pounds per Cubic Yard*

| Kind | Sp. Gr. | Loose Spread 45% Voids | Compacted 30% Voids |
|---|---|---|---|
| Trap | 2.8 | 2590 | 3300 |
| | 2.9 | 2680 | 3420 |
| | 3.0 | 2770 | 3540 |
| | 3.1 | 2870 | 3650 |
| Granite | 2.6 | 2400 | 3060 |
| | 2.7 | 2500 | 3180 |
| | 2.8 | 2590 | 3300 |
| Limestone | 2.6 | 2400 | 3060 |
| | 2.7 | 2500 | 3180 |
| | 2.8 | 2590 | 3300 |
| Sandstone | 2.4 | 2220 | 2830 |
| | 2.5 | 2310 | 2940 |
| | 2.6 | 2400 | 3060 |
| | 2.7 | 2500 | 3180 |

### Gravel and Sand

*Approximate Number of Pounds per Cubic Yard*

| Voids | Weight | Voids | Weight |
|---|---|---|---|
| 50% | 2240 | 35% | 2910 |
| 45% | 2460 | 30% | 3130 |
| 40% | 2680 | 25% | 3350 |

* *From Pocket Reference for Highway Engineers, Asphalt Institute.*

## TABLE 45. WEIGHT AND VOLUME RELATIONS OF ASPHALTIC MATERIALS AT 60° F. *

| Specific Gravity | Pounds per Gallon | Gallons per Ton | Specific Gravity | Pounds per Gallon | Gallons per Ton | Specific Gravity | Pounds per Gallon | Gallons per Ton |
|---|---|---|---|---|---|---|---|---|
| 0.930 | 7.745 | 258.2 | 0.980 | 8.162 | 245.0 | 1.030 | 8.578 | 233.2 |
| 0.935 | 7.786 | 256.8 | 0.985 | 8.203 | 243.8 | 1.035 | 8.620 | 232.0 |
| 0.940 | 7.828 | 255.6 | 0.990 | 8.245 | 242.6 | 1.040 | 8.662 | 230.8 |
| 0.945 | 7.870 | 254.2 | 0.995 | 8.287 | 241.4 | 1.045 | 8.704 | 229.8 |
| 0.950 | 7.911 | 252.8 | 1.000 | 8.328 | 240.2 | 1.050 | 8.745 | 228.6 |
| 0.955 | 7.953 | 251.4 | 1.005 | 8.370 | 239.0 | 1.055 | 8.787 | 227.6 |
| 0.960 | 7.995 | 250.2 | 1.010 | 8.412 | 237.8 | 1.10 | 9.161 | 218.3 |
| 0.965 | 8.036 | 248.8 | 1.015 | 8.453 | 236.6 | 1.20 | 9.994 | 200.1 |
| 0.970 | 8.078 | 247.6 | 1.020 | 8.495 | 235.4 | 1.30 | 10.826 | 184.8 |
| 0.975 | 8.120 | 246.4 | 1.025 | 8.537 | 234.2 | 1.40 | 11.659 | 171.6 |

* *From Principles of Highway Construction, Public Roads Administration.*

## TABLE 46. DISTANCE IN LINEAL FEET COVERED BY A 1000-GALLON DISTRIBUTOR TANK LOAD *

| Application Rate, gallons per square yard | Width of Spread, feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 0.1 | 45,000 | 30,000 | 22,500 | 18,000 | 15,000 | 12,857 | 11,250 | 10,000 | 9000 | 8182 |
| 0.15 | 30,000 | 20,000 | 15,000 | 12,000 | 10,000 | 8,571 | 7,500 | 6,667 | 6000 | 5455 |
| 0.2 | 22,500 | 15,000 | 11,250 | 9,000 | 7,500 | 6,429 | 5,625 | 5,000 | 4500 | 4091 |
| 0.25 | 18,000 | 12,000 | 9,000 | 7,200 | 6,000 | 5,143 | 4,500 | 4,000 | 3000 | 3273 |
| 0.3 | 15,000 | 10,000 | 7,500 | 6,000 | 5,000 | 4,286 | 3,750 | 3,333 | 3000 | 2727 |
| 0.333 | 13,500 | 9,000 | 6,750 | 5,400 | 4,500 | 3,857 | 3,375 | 3,000 | 2700 | 2455 |
| 0.35 | 12,857 | 8,571 | 6,429 | 5,143 | 4,286 | 3,673 | 3,214 | 2,857 | 2571 | 2338 |
| 0.4 | 11,250 | 7,500 | 5,625 | 4,500 | 3,750 | 3,214 | 2,813 | 2,500 | 2250 | 2045 |
| 0.45 | 10,000 | 6,667 | 5,000 | 4,000 | 3,333 | 2,857 | 2,500 | 2,222 | 2000 | 1818 |
| 0.5 | 9,000 | 6,000 | 4,500 | 3,600 | 3,000 | 2,571 | 2,250 | 2,000 | 1800 | 1636 |
| 0.6 | 7,500 | 5,000 | 3,750 | 3,000 | 2,500 | 2,143 | 1,875 | 1,667 | 1500 | 1364 |
| 0.667 | 6,750 | 4,500 | 3,375 | 2,700 | 2,250 | 1,929 | 1,688 | 1,500 | 1350 | 1227 |
| 0.7 | 6,429 | 4,286 | 3,214 | 2,571 | 2,143 | 1,837 | 1,607 | 1,429 | 1286 | 1169 |
| 0.75 | 6,000 | 4,000 | 3,000 | 2,400 | 2,000 | 1,714 | 1,500 | 1,333 | 1200 | 1091 |
| 0.8 | 5,625 | 3,750 | 2,813 | 2,250 | 1,875 | 1,607 | 1,406 | 1,250 | 1125 | 1023 |
| 0.9 | 5,000 | 3,333 | 2,500 | 2,000 | 1,667 | 1,429 | 1,250 | 1,111 | 1000 | 909 |
| 1.0 | 4,500 | 3,000 | 2,250 | 1,800 | 1,500 | 1,286 | 1,125 | 1,000 | 900 | 818 |
| 1.25 | 3,600 | 2,400 | 1,800 | 1,440 | 1,200 | 1,029 | 900 | 800 | 720 | 655 |
| 1.5 | 3,000 | 2,000 | 1,500 | 1,200 | 1,000 | 857 | 750 | 667 | 600 | 545 |
| 1.75 | 2,571 | 1,714 | 1,286 | 1,029 | 857 | 735 | 643 | 571 | 514 | 468 |
| 2.0 | 2,250 | 1,500 | 1,125 | 900 | 750 | 643 | 563 | 500 | 450 | 409 |
| 2.25 | 2,000 | 1,333 | 1,000 | 800 | 667 | 571 | 500 | 444 | 400 | 364 |
| 2.5 | 1,800 | 1,200 | 900 | 720 | 600 | 514 | 450 | 400 | 360 | 327 |

| Application Rate, gallons per square yard | Width of Spread, feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 0.1 | 7500 | 6923 | 6429 | 6000 | 5625 | 5294 | 5000 | 4737 | 4500 |
| 0.15 | 5000 | 4615 | 4286 | 4000 | 3750 | 3529 | 3333 | 3158 | 3000 |
| 0.2 | 3750 | 3462 | 3214 | 3000 | 2813 | 2647 | 2500 | 2368 | 2250 |
| 0.25 | 3000 | 2769 | 2571 | 2400 | 2250 | 2118 | 2000 | 1895 | 1800 |
| 0.3 | 2500 | 2308 | 2143 | 2000 | 1875 | 1765 | 1667 | 1579 | 1500 |
| 0.333 | 2250 | 2077 | 1929 | 1800 | 1688 | 1588 | 1500 | 1421 | 1350 |
| 0.35 | 2143 | 1978 | 1837 | 1714 | 1607 | 1513 | 1429 | 1353 | 1286 |
| 0.4 | 1875 | 1731 | 1607 | 1500 | 1406 | 1324 | 1250 | 1184 | 1125 |
| 0.45 | 1667 | 1538 | 1429 | 1333 | 1250 | 1176 | 1111 | 1053 | 1000 |
| 0.5 | 1500 | 1385 | 1286 | 1200 | 1125 | 1059 | 1000 | 947 | 900 |
| 0.6 | 1250 | 1154 | 1071 | 1000 | 938 | 882 | 833 | 789 | 750 |
| 0.667 | 1125 | 1038 | 964 | 900 | 844 | 794 | 750 | 711 | 675 |
| 0.7 | 1071 | 989 | 918 | 857 | 804 | 756 | 714 | 677 | 643 |
| 0.75 | 1000 | 923 | 857 | 800 | 750 | 706 | 667 | 632 | 600 |
| 0.8 | 938 | 865 | 804 | 750 | 703 | 662 | 625 | 592 | 563 |
| 0.9 | 833 | 769 | 714 | 667 | 625 | 588 | 556 | 526 | 500 |
| 1.0 | 750 | 692 | 643 | 600 | 563 | 529 | 500 | 474 | 450 |
| 1.25 | 600 | 554 | 514 | 480 | 450 | 424 | 400 | 379 | 360 |
| 1.5 | 500 | 462 | 429 | 400 | 375 | 353 | 333 | 316 | 300 |
| 1.75 | 429 | 396 | 367 | 343 | 321 | 303 | 286 | 271 | 257 |
| 2.0 | 375 | 346 | 321 | 300 | 281 | 265 | 250 | 237 | 225 |
| 2.25 | 333 | 308 | 286 | 267 | 250 | 235 | 222 | 211 | 200 |
| 2.5 | 300 | 277 | 257 | 240 | 225 | 212 | 200 | 189 | 180 |

* *From Principles of Highway Construction, Public Roads Administration.*

**TABLE 47. STANDARD ABRIDGED VOLUME CORRECTION TABLE FOR BITUMINOUS MATERIALS ***

[Volume at 60° F. occupied by unit volume at indicated temperature; $t$ = observed temperature °F.; $M$ = multiplier to reduce volume to 60° F.]

GROUP 0. SPECIFIC GRAVITY AT 60° F., ABOVE 0.966

| $t$ | $M$ | $t$ | $M$ | $t$ | $M$ | $t$ | $M$ |
|---|---|---|---|---|---|---|---|
| 60 | 1.0000 | 145 | 0.9707 | 230 | 0.9425 | 315 | 0.9154 |
| 65 | .9982 | 150 | .9691 | 235 | .9409 | 320 | .9138 |
| 70 | .9965 | 155 | .9674 | 240 | .9392 | 325 | .9123 |
| 75 | .9948 | 160 | .9657 | 245 | .9376 | 330 | .9107 |
| 80 | .9931 | 165 | .9640 | 250 | .9360 | 335 | .9092 |
| 85 | .9914 | 170 | .9623 | 255 | .9344 | 340 | .9076 |
| 90 | .9896 | 175 | .9606 | 260 | .9328 | 345 | .9061 |
| 95 | .9879 | 180 | .9590 | 265 | .9312 | 350 | .9045 |
| 100 | .9862 | 185 | .9573 | 270 | .9296 | 355 | .9030 |
| 105 | .9844 | 190 | .9556 | 275 | .9280 | 360 | .9014 |
| 110 | .9827 | 195 | .9539 | 280 | .9264 | 365 | .8999 |
| 115 | .9809 | 200 | .9523 | 285 | .9248 | 370 | .8984 |
| 120 | .9792 | 205 | .9507 | 290 | .9233 | 375 | .8969 |
| 125 | .9775 | 210 | .9490 | 295 | .9217 | 380 | .8953 |
| 130 | .9758 | 215 | .9474 | 300 | .9201 | 385 | .8938 |
| 135 | .9741 | 220 | .9458 | 305 | .9185 | 390 | .8923 |
| 140 | .9724 | 225 | .9441 | 310 | .9169 | 395 | .8908 |
| | | | | | | 400 | .8893 |

GROUP 1. SPECIFIC GRAVITY AT 60° F., 0.850 TO 0.966

| $t$ | $M$ | $t$ | $M$ | $t$ | $M$ | $t$ | $M$ |
|---|---|---|---|---|---|---|---|
| 60 | 1.0000 | 145 | 0.9667 | 230 | 0.9345 | 315 | 0.9034 |
| 65 | .9980 | 150 | .9647 | 235 | .9326 | 320 | .9016 |
| 70 | .9960 | 155 | .9628 | 240 | .9307 | 325 | .8998 |
| 75 | .9940 | 160 | .9608 | 245 | .9289 | 330 | .8980 |
| 80 | .9921 | 165 | .9590 | 250 | .9270 | 335 | .8962 |
| 85 | .9901 | 170 | .9570 | 255 | .9252 | 340 | .8945 |
| 90 | .9881 | 175 | .9551 | 260 | .9234 | 345 | .8927 |
| 95 | .9861 | 180 | .9532 | 265 | .9215 | 350 | .8909 |
| 100 | .9841 | 185 | .9513 | 270 | .9197 | 355 | .8892 |
| 105 | .9822 | 190 | .9494 | 275 | .9179 | 360 | .8874 |
| 110 | .9803 | 195 | .9476 | 280 | .9160 | 365 | .8856 |
| 115 | .9783 | 200 | .9457 | 285 | .9142 | 370 | .8839 |
| 120 | .9763 | 205 | .9438 | 290 | .9124 | 375 | .8821 |
| 125 | .9744 | 210 | .9419 | 295 | .9106 | 380 | .8804 |
| 130 | .9724 | 215 | .9401 | 300 | .9088 | 385 | .8786 |
| 135 | .9705 | 220 | .9382 | 305 | .9070 | 390 | .8769 |
| 140 | .9686 | 225 | .9363 | 310 | .9052 | 395 | .8752 |
| | | | | | | 400 | .8734 |

GROUP 00. TAR PRODUCTS, A.A.S.H.O.
GRADES RT-5, RT-6, RT-7, RT-8, RT-9, RT-10, RT-11, RT-12, RTCB-5, RTCB-6

| $t$ | $M$ | $t$ | $M$ | $t$ | $M$ | $t$ | $M$ |
|---|---|---|---|---|---|---|---|
| 60 | 1.0000 | 105 | 0.9867 | 155 | 0.9723 | 205 | 0.9583 |
| 65 | .9985 | 110 | .9852 | 160 | .9709 | 210 | .9569 |
| 70 | .9970 | 115 | .9838 | 165 | .9695 | 215 | .9556 |
| 75 | .9955 | 120 | .9823 | 170 | .9681 | 220 | .9542 |
| 80 | .9940 | 125 | .9809 | 175 | .9667 | 225 | .9528 |
| 85 | .9926 | 130 | .9794 | 180 | .9653 | 230 | .9515 |
| 90 | .9911 | 135 | .9780 | 185 | .9639 | 235 | .9501 |
| 95 | .9896 | 140 | .9766 | 190 | .9625 | 240 | .9488 |
| 100 | .9881 | 145 | .9751 | 195 | .9611 | 245 | .9474 |
| | | 150 | .9737 | 200 | .9597 | 250 | .9461 |

* *From Principles of Highway Construction, Public Roads Administration.*

**TABLE 48. AMOUNTS OF MATERIAL PER SQUARE YARD FOR A TYPICAL PENETRATION MACADAM SURFACE ***

| | Base | | Surface | |
|---|---|---|---|---|
| | Size | Amount | Size | Amount |
| Coarse stone | 3 to 2 in. | 285 lb. | 2½ to 1½ in. | 270 lb. |
| Bitumen | | 1.85 gal. | | 1.5 gal. |
| Medium stone | 1 to ¾ in. | 30 lb. | ¾ in. to No. 4 | 30 lb. |
| Bitumen | | 0.3 gal. | | 0.5 gal. |
| Fine stone | 1 to ¾ in. | 25 lb. | ¾ in. to No. 4 | 25 lb. |
| Bitumen | | | | 0.3 gal. |
| Stone chips | ½ in. to No. 4 | 10 lb. | ⅜ in. to No. 8 | 15 lb. |
| Do | | | ⅜ in. to No. 8 | 10 lb. |
| Total aggregate | | 350 lb. | | 350 lb. |
| Total bitumen | | 2.15 gal. | | 2.3 gal. |

* *From Principles of Highway Construction, Public Roads Administration.*

Date *June 10* 194 *0* Report No. *12*

S. P. No. *2006–05*

Engineer F. A. P. No. *174*

DAILY BITUMINOUS REPORT (CONSTRUCTION) *

FOR MACADAM, BITUM. TREATMENTS, MIX-IN-PLACE

T. H. No. *56* From *West Concord* To *Jct. T.H. 14*

Inspector *A. C. Johnson* Contractor *Pioneer Co.*

| Course | Station | | Aggregate Lb. per Sq. Yd. | Bituminous Material | | Application Temperature | Width of Material |
|---|---|---|---|---|---|---|---|
| | From | To | | Gal. per Sq. Yd. | Per cent of Mix | | |
| *Base prime* | *326 + 00* | *356 + 00* | | *0.22* | | *110°* | *26′* |
| *Wearing* | *256 + 00* | *308 + 00* | *150* | *0.88* | *4.6* | *200°* | *24′* |
| *Wearing* | *308 + 00* | *326 + 00* | *100* | *0.60* | *4.7* | *200°* | *24′* |
| *Tack* | *308 + 00* | *326 + 00* | | *0.07* | | *200°* | *24′* |
| *Seal* | *0 + 00* | *56 + 00* | *18* | *0.30* | | *220°* | *24′* |

AGGREGATE GRADING

| Course | Pit No. or Station | Total Per Cent Passing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ¾ | ⅝ | ⅜ | *10* | *20* | *40* | *100* | *200* | |
| *Wearing* | *506* | *100* | *98* | *80* | *47* | | *18* | | *3.1* | |
| *Wearing* | *506* | *100* | *97* | *80* | *51* | | *19* | | *3.4* | |
| *Seal* | *Doe Gravel Co.* | | | *100* | *5.0* | *2.0* | | | | |

BITUMINOUS MATERIALS USED

| Course | Kind and Grade | Gallons Applied | | |
|---|---|---|---|---|
| | | Today | Prev. | To Date |
| *Base prime* | *MC – 1* | *1,700* | *10,100* | *11,800* |
| *Tack* | *MC – 3* | *350* | *1,200* | *1,550* |
| *Wearing* | *MC – 3* | *25,300* | *101,000* | *126,300* |
| *Seal* | *RT – 9* | *4,450* | *15,000* | *19,450* |

Weather A.M. *clear* P.M. *clear*
Temperature 8 A.M. *67* 12 N. *85* 5 P.M. *78*

EQUIPMENT

| Description | No. Units | Hours Worked |
|---|---|---|
| *Traveling plant* | *1* | *15* |
| *Distributor* | *1* | *8* |
| *Trucks* | *5* | *40* |
| *Blade graders* | *3* | *24* |
| *Roller* | *1* | *10* |
| *Chip spreader* | *1* | *3* |
| *Sweeper* | *1* | *5* |
| *Drag broom* | *1* | *3* |
| *Transfer tank* | *1* | *15* |

OPERATING TIME AND DELAYS

Time start *4:00* A.M. Time stop *7:30* P.M. Gross time *15½* Time delayed *½* Net operating time *15*

| Delays due to | *Lunch ½ hr.* |
|---|---|

Remarks: *Aggregate mixed and coated very well.*

Signed by *J. M. Smith*
Project Engineer

* *From Minnesota State Highway Department.*

Date ______ ______ Engineer Report No. ______

Type of pavement ______ PLANT-MIX BITUMINOUS INSPECTION S. P. No. ______

Width ______ DAILY PAVING REPORT * F. A. P. No. ______

T. H. No. ______ From ______ To ______ Length ______

Engineer ______ Contractor ______

Street inspector ______ Plant inspector ______

| Course | Station | | Tons Mixture Placed | Area in Sq. Yd. | Yield Lb. per Sq. Yd. | Temperature When Laid |
|---|---|---|---|---|---|---|
| | From | To | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Total | | | | | | |

EQUIPMENT

| Spreading Machine | | | Total Hours Worked |
|---|---|---|---|
| Make and type | No. | Width | |
| | | | |
| Rollers | | | |
| Make and type | No. | Wt. | |
| | | | |
| Other Equipment | | | |
| Description | | No. | |
| | | | |

PLACING AND FINISHING

| | Good | Fair | Poor | Remarks |
|---|---|---|---|---|
| Workability | | | | |
| Temperature | | | | |
| Spreading | | | | |
| Shoveling | | | | |
| Raking | | | | |
| Rolling | | | | |
| Finished surface | | | | |

HAUL DATA

Average round-trip time ______ Min.
Average length of haul ______ Miles

WEATHER AND TEMPERATURE

Weather: A.M. ______ P.M. ______
Temperature: 7:00 A.M. ______ 10:00 A.M. ______
2:00 P.M. ______ 5:00 P.M. ______

TIME DISTRIBUTION AND DELAYS

Time start ______ Time stop ______ Gross time ______ Time delayed ______ Net paving time ______

| Moving | Weather | Non wk. days | Rock | Sand | Filler | Bit. cement | Chips |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Paver | Plant | Switching | Haul road | Trucks | Rollers | Base | |
| | | | | | | | |

Remarks ______

______

Signed by ______
Project Engineer

* *From Minnesota State Highway Department.*

Engineer

Date ________ Report No. ________

Type of Pavement ________ PLANT-MIX BITUMINOUS INSPECTION S. P. No. ________

F. A. P. No. ________

DAILY PLANT REPORT *

T. H. No. ________ From ________ To ________ Length ________

Contractor ________ Location of plant ________ Type of plant ________

Engineer ________ Plant inspector ________ Street inspector ________

BATCH PROPORTIONS

| | Wearing Course | | | | Binder Course | | | |
|---|---|---|---|---|---|---|---|---|
| | Lb. | Per Cent | Lb. | Per Cent | Lb. | Per Cent | Lb. | Per Cent |
| Sand | | | | | | | | |
| Filler | | | | | | | | |
| Bit. cem. | | | | | | | | |
| Batch totals | | | | | | | | |
| Tons Mixed | | | | | | | | |

AGGREGATE GRADINGS

| | Separate Bins | | | | | Composite Grading | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Sand | Filler | Wearing C. | | Binder C. | |
| Total % Passing | | | | | | | | | |
| " 1½ | | | | | | | | | |
| " 1¼ | | | | | | | | | |
| " 1 | | | | | | | | | |
| " ¾ | | | | | | | | | |
| " ⅝ | | | | | | | | | |
| " ⅜ | | | | | | | | | |
| " 4 | | | | | | | | | |
| " 10 | | | | | | | | | |
| " 20 | | | | | | | | | |
| " 40 | | | | | | | | | |
| " 80 | | | | | | | | | |
| " 100 | | | | | | | | | |
| " 200 | | | | | | | | | |

MATERIALS USED

| | Source | Tons Today | Tons Prev. | Tons to Date |
|---|---|---|---|---|
| Coarse agg. | | | | |
| Fine agg. | | | | |
| Filler | | | | |
| Bit. cement | | | | |
| Totals | | | | |

TEMPERATURES

| | Max. | Min. | Aver. |
|---|---|---|---|
| C. Agg. | | | |
| Fine agg. | | | |
| Bit. cement | | | |
| Wear. course | | | |
| Binder course | | | |

MIXING TIME

Mixing time ________ Sec.

Spec. req. min. ________ Sec.

Time start ________ Time stop ________ Gross time ________ Time delayed ________ Net operating time ________

Remarks: ________

Signed by ________

Project engineer

* From Minnesota State Highway Department.

______________________
Engineer

BITUMINOUS PAVING ANALYSES *

______________194

*Client* ______________________

*Project* ______________________

*Material* ______________________

| | | | |
|---|---|---|---|
| Report No. | | | |
| Job sample No. | | | |
| Date laid | | | |
| Sampled by | | | |
| Taken at | | | |

| SCREENS AND SIEVES USED | ANALYSES | | REQUIRED Min. % | Max. % |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Passing 200 Mesh Filler | | | | |
| Bitumen content | | | | |

Remarks:

______________________
Inspector

* *From Haller Engineering Associates, Inc.*

________________________
Engineer

## ASPHALT REPORT *

Report for ________________________
Material ________________________
Project ________________________
Producer ________________________
Contractor ____________ Quantity ____________
Shipped via ____________ Report No. ______ Date ____

| | | | | |
|---|---|---|---|---|
| Specific gravity @ 25° C. | | | | |
| Flash point degrees F. (open cup) | | | | |
| Asphalt content @ 100 pen. | | | | |
| Furol viscosity @ ° C. | | | | |
| Penetration 25° C. 100 g. 5 sec. | | | | |
| Ductility, centimeters @ 25° C. | | | | |
| Loss on evaporation 163° C. 5 hr. | | | | |
| Penetration of residue from evaporation 25° C. 100 g. 5 sec. | | | | |
| Total distillate % by volume to 320° F. (160° C.) | | | | |
| Total distillate % by volume to 374° F. (190° C.) | | | | |
| Total distillate % by volume to 437° F. (225° C.) | | | | |
| Total distillate % by volume to 600° F. (315° C.) | | | | |
| Total distillate % by volume to 680° F. (360° C.) | | | | |
| Penetration residue from Distillation 25° C. 100 g. 5 sec. | | | | |
| Ductility residue from Distillation cm. @ 25° C. | | | | |
| Total bitumen (soluble in $CS_2$) | | | | |
| | | | | |

Remarks:

The above fulfills the specification requirements.

________________________
Inspector

* *From Haller Engineering Associates, Inc.*

## CHECK LIST FOR INSPECTORS

## SANITARY CONSTRUCTION

**Inspectors' Equipment**

Complete working drawings with accurate dimensions covering anchor bolts, sleeves, flexible couplings, expansion loops, etc., with adequate clearances for erection.

**Procedure in Inspection**

Anchor-bolt locations and wall castings should be checked for accuracy; make sure bolt threads are clean and not damaged.

Sufficient flexible couplings, sleeves, expansion loops, and similar fittings should be provided to reduce vibration and facilitate erection and dismantling of equipment and piping.

Base plates of machines should be set accurately and blocked, not grouted in until assembly of machine is complete. Adjust to level again and grout into position.

Check lubrication of all machines before operating. If equipment has stood around for a period, flushing oil should be used to remove sediment.

Flush out pipe lines, particularly sludge lines from clarifiers. Make sure there are no blocks of lumber, bits of concrete, or other debris in these lines to obstruct a clear passage.

Capacity tests should be run on centrifugal pumps by using a tank (clarifier, wet well, etc.).

Check weirs, making sure they are level.

Review erection instructions of equipment manufacturer, and check to see they have been followed.

Make sure motors are rotating in right direction for the equipment.

Where possible rotate motor and reducer by hand to make sure bearings are free.

Check seal in distributor to see that mercury has been placed properly.

Check gas-utilization equipment to make sure that drainage traps are correctly installed and valves prevent gas escape; that meters are not filled with water; that counterweights in relief devices are correct in size and function freely; that entire hook-up is installed correctly.

In high-rate filter plants, check size, grading, and cleanliness of rock. Dirt and undersized particles should not be allowed.

**Pipe Laying.** See p. 180.

**Filter sands** should be carefully controlled to fit the requirements of the specifications.

Take and send frequent samples to the laboratory for test for effective size and uniformity coefficient, or make these tests in the field; see p. 125.

Samples of sand should be taken by the quartering method; see p. 10.

See sections on Concrete, Structural Steel, Timber, Masonry, Welding, etc., for those particular phases of the work.

# PIPE LAYING

## PIPE

### TABLE 49. CEMENT-ASBESTOS SEWER PIPE (TRANSITE)

| Pipe Size (inside diameter), inches | Class 1 | | | Class 2 | | | Class 3 | | | Class 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shell Thickness, inches | Weight per Lin. Ft., lb. | Ultimate Strength 3-edge Bearing, lb. per lin. ft. | Shell Thickness, inches | Weight per Lin. Ft., lb. | Ultimate Strength 3-edge Bearing, lb. per lin. ft. | Shell Thickness, inches | Weight per Lin. Ft., lb. | Ultimate Strength 3-Edge Bearing, lb. per lin. ft. | Shell Thickness, inches | Weight per Lin. Ft., lb. | Ultimate Strength 3-Edge Bearing, lb. per lin. ft. |
| 4 | 0.39 | 4.9 | 4,125 | | | | | | | | | |
| 6 | 0.42 | 7.9 | 2,880 | | | | | | | | | |
| 8 | 0.48 | 11.9 | 3,100 | | | | | | | | | |
| 10 | 0.50 | 15.3 | 2,580 | 0.56 | 17.7 | 3,690 | 0.65 | 21.0 | 4,920 | | | |
| 12 | 0.54 | 19.9 | 2,370 | 0.64 | 23.6 | 3,850 | 0.74 | 28.6 | 5,100 | | | |
| 14 | 0.58 | 24.6 | 2,200 | 0.73 | 31.0 | 3,920 | 0.84 | 37.0 | 5,150 | | | |
| 16 | 0.62 | 30.2 | 2,120 | 0.82 | 40.6 | 4,050 | 0.94 | 47.8 | 5,280 | | | |
| 18 | 0.65 | 35.5 | 2,030 | 0.90 | 51.0 | 4,140 | 1.03 | 58.0 | 5,360 | 1.12 | 66.0 | 6,340 |
| 20 | 0.69 | 41.7 | 2,290 | 0.94 | 57.5 | 4,280 | 1.13 | 70.0 | 5,850 | 1.25 | 84.0 | 7,100 |
| 24 | 0.75 | 54.3 | 2,340 | 1.06 | 77.6 | 4,550 | 1.31 | 100.0 | 7,050 | 1.45 | 110.0 | 8,600 |
| 30 | 0.96 | 86.8 | 2,980 | 1.24 | 113.2 | 5,000 | 1.64 | 155.0 | 8,180 | 1.85 | 175.0 | 10,450 |
| 36 | 1.15 | 124.8 | 3,500 | 1.41 | 154.3 | 5,400 | 1.93 | 215.0 | 9,700 | 2.18 | 248.0 | 12,300 |

Standard laying length, 13 ft.
Furnished only in straight lengths.
Cast-iron fittings recommended for branch connections.

Ultimate strengths determined by tests made in accordance with procedure of A.S.T.M.
All data furnished by Johns-Manville Corp.

## TABLE 50. CLAY PIPE, STANDARD STRENGTH, A.S.T.M. SPEC. C-13

| Size, in. | Laying Length | | Maximum Difference in Length of Two Opposite Sides, in. | Outside Diameter of Barrel, in. | | Inside Diameter of Socket at ½ in. above Base, in. | | Depth of Socket, in. | | Thickness of Barrel, in. | | Thickness of Socket at ½ in. from Outer End, in. | | Average Strength Requirements, min., lb. per lin. ft. | | Weight per foot of Pipe * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nominal, ft. | Limit of Minus Variation,[a] in. per ft. of length | | Min. | Max. | Min. | Max. | Nominal | Min. | Nominal | Min. | Nominal | Min. | Three-Edge-Bearing Method | Sand-Bearing Method | |
| 4 | 2, 2½, 3 | ¼ | 5/16 | 4⅞ | 5⅛ | 5¾ | 6⅛ | 1¾ | 1½ | ½ | 7/16 | 7/16 | ⅜ | 1000 | 1430 | 9.0 |
| 6 | 2, 2½, 3 | ¼ | ⅜ | 7 1/16 | 7 7/16 | 8 3/16 | 8⅝ | 2¼ | 2 | ⅝ | 9/16 | ½ | 7/16 | 1000 | 1430 | 15.5 |
| 8 | 2, 2½, 3 | ¼ | 7/16 | 9¼ | 9¾ | 10½ | 11 | 2½ | 2¼ | ¾ | 11/16 | 9/16 | ½ | 1000 | 1430 | 23.8 |
| 10 | 2, 2½, 3 | ¼ | 7/16 | 11½ | 12 | 12¾ | 13¼ | 2⅝ | 2⅜ | ⅞ | 13/16 | ⅝ | 9/16 | 1100 | 1570 | 33.8 |
| 12 | 2, 2½, 3 | ¼ | 7/16 | 13¾ | 14 5/16 | 15⅛ | 15¾ | 2¾ | 2½ | 1 | 15/16 | ¾ | 11/16 | 1200 | 1710 | 46.8 |
| 15 | 3, 4 | ¼ | ½ | 17 3/16 | 17 13/16 | 18⅝ | 19¼ | 2⅞ | 2⅝ | 1¼ | 1⅛ | 15/16 | ⅞ | 1400 | 2000 | 67.7 |
| 18 | 3, 4 | ¼ | ½ | 20⅝ | 21 7/16 | 22¼ | 23 | 3 | 2¾ | 1½ | 1⅜ | 1⅛ | 1 1/16 | 1700 | 2430 | 97.7 |
| 21 | 3, 4 | ¼ | 9/16 | 24⅛ | 25 | 25⅞ | 26¾ | 3¼ | 3 | 1¾ | 1⅝ | 1 5/16 | 1 3/16 | 2000 | 2860 | 139 |
| 24 | 3, 4 | ⅜ | 9/16 | 27½ | 28½ | 29⅜ | 30⅜ | 3⅜ | 3⅛ | 2 | 1⅞ | 1½ | 1⅜ | 2400 | 3430 | 180 |
| 27 | 3, 4 | ⅜ | 9/16 | 31 | 32⅛ | 33 | 34⅛ | 3½ | 3¼ | 2¼ | 2⅛ | 1 11/16 | 1 9/16 | 2750 | 3930 | |
| 30 | 3, 4 | ⅜ | ⅝ | 34⅜ | 35⅝ | 36½ | 37¾ | 3⅝ | 3⅜ | 2½ | 2⅜ | 1⅞ | 1¾ | 3200 | 4570 | 277 |
| 33 | 3, 4 | ⅜ | ⅝ | 37⅝ | 38 15/16 | 39⅞ | 41¼ | 3¾ | 3½ | 2⅝ | 2½ | 2 | 1 13/16 | 3500 | 5000 | |
| 36 | 3, 4 | ⅜ | 1 1/16 | 40¾ | 42¼ | 43¼ | 44¾ | 4 | 3¾ | 2¾ | 2⅝ | 2 1/16 | 1⅞ | 3900 | 5570 | 392 |

[a] There is no limit for plus variation.

* *From Robinson Clay Products Co.*

# TABLE 51. CLAY PIPE, EXTRA STRENGTH, A.S.T.M. SPEC. C-200

| Nominal Size, in. | Laying Length | | Maximum Difference in Length of Two Opposite Sides, in. | Outside Diameter of Barrel,[b] in. | | Inside Diameter of Socket at 1/2 in. above Base, in. | | Depth of Socket, in. | | Thickness of Barrel, in. | | Thickness of Socket at 1/2 in. from Outer End, in. | | Average Strength Requirements, min., lb. per lin. ft. | | Weight per Foot of Pipe * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nominal, ft. | Limit of Minus Variation,[a] in. per ft. of length | | Min. | Max. | Min. | Max. | Nominal | Min. | Nominal | Min. | Nominal | Min. | Three-Edge-Bearing Method | Sand-Bearing Method | |
| 6 | 2, 2 1/2, 3 | 1/4 | 3/8 | 7 1/16 | 7 7/16 | 8 3/16 | 8 5/8 | 2 1/4 | 2 | 11/16 | 9/16 | 1/2 | 7/16 | 2000 | 2850 | 16 |
| 8 | 3 | 1/4 | 7/16 | 9 1/4 | 9 3/4 | 10 1/2 | 11 | 2 1/2 | 2 1/4 | 7/8 | 3/4 | 9/16 | 1/2 | 2000 | 2850 | 26 |
| 10 | 3 | 1/4 | 7/16 | 11 1/2 | 12 | 12 3/4 | 13 1/4 | 2 5/8 | 2 3/8 | 1 | 7/8 | 5/8 | 9/16 | 2000 | 2850 | 38 |
| 12 | 3 | 1/4 | 7/16 | 13 3/4 | 14 5/16 | 15 1/8 | 15 3/4 | 2 3/4 | 2 1/2 | 1 3/16 | 1 1/16 | 3/4 | 11/16 | 2250 | 3200 | 54 |
| 15 | 3, 4 | 1/4 | 1/2 | 17 3/16 | 17 13/16 | 18 5/8 | 19 1/4 | 2 7/8 | 2 5/8 | 1 1/2 | 1 3/8 | 15/16 | 7/8 | 2750 | 3925 | 78 |
| 18 | 3, 4 | 1/4 | 1/2 | 20 5/8 | 21 7/16 | 22 1/4 | 23 | 3 | 2 3/4 | 1 7/8 | 1 3/4 | 1 1/8 | 1 1/16 | 3300 | 4700 | 124 |
| 21 | 3, 4 | 1/4 | 9/16 | 24 1/8 | 25 | 25 7/8 | 26 3/4 | 3 1/4 | 3 | 2 1/4 | 2 | 1 5/16 | 1 3/16 | 3850 | 5500 | 170 |
| 24 | 3, 4 | 3/8 | 9/16 | 27 1/2 | 28 1/2 | 29 3/8 | 30 3/8 | 3 3/8 | 3 1/8 | 2 1/2 | 2 1/4 | 1 1/2 | 1 3/8 | 4400 | 6300 | 214 |
| 30 | 3, 4 | 3/8 | 5/8 | 34 3/8 | 35 5/8 | 36 1/2 | 37 3/4 | 3 5/8 | 3 3/8 | 3 | 2 3/4 | 1 7/8 | 1 3/4 | 5000 | 7100 | 323 |
| 36 | 3, 4 | 3/8 | 11/16 | 40 3/4 | 42 1/4 | 43 1/4 | 44 3/4 | 4 | 3 3/4 | 3 1/2 | 3 1/4 | 2 1/16 | 1 7/8 | 6000 | 8575 | 444 |

[a] There is no limit for plus variation.

[b] The average actual inside diameters of pipe having the nominal thickness of barrel shown in Table 53 may be smaller than the nominal sizes.

* *From Robinson Clay Products Co.*

**TABLE 52. CORRUGATED METAL CULVERT PIPE**

| Inside Pipe Diameter, in. | Weight per Linear Foot, lb. 16 Gage | 14 Gage | 12 Gage | 10 Gage | 8 Gage |
|---|---|---|---|---|---|
| 4 | | | | | |
| 6 | | | | | |
| 8 | 7.6 | 9.3 | | | |
| 10 | 9.3 | 11.4 | | | |
| 12 | 10.8 | 13.3 | 18.5 | | |
| 15 | 13.3 | 16.4 | 22.7 | | |
| 18 | 15.8 | 19.5 | 27.0 | | |
| 21 | 18.3 | 22.5 | 31.2 | 39.7 | |
| 24 | 21.0 | 26.0 | 35.9 | 45.7 | |
| 30 | | 31.7 | 43.9 | 55.9 | |
| 36 | | 37.9 | 52.4 | 66.7 | 81.1 |
| 42 | | 44.4 | 61.5 | 78.3 | 95.1 |
| 48 | | 50.5 | 70.0 | 89.1 | 108.3 |
| 54 | | 57.8 | 80.1 | 102.0 | 123.9 |
| 60 | | | 88.2 | 112.3 | 136.4 |
| 66 | | | 96.6 | 123.1 | 149.5 |
| 72 | | | 105.1 | 133.9 | 162.6 |
| 84 | | | | 156.6 | 190.3 |

Furnished in any length in multiples of 2 ft.
Data furnished for Armco Pipe by Shelt Co., Elmira, N. Y.

## TABLE 53. NON-REINFORCED-CONCRETE SEWER PIPE, A.S.T.M. C-14-41

| Internal Diameter, $D$, in. | Laying Length, $L$, ft. | Inside Diameter at Mouth of Socket, $D_s$, in.[a] | Depth of Socket, $L_s$, in. | Minimum Taper of Socket, $H$ | Thickness of Barrel, $T$, in. | Thickness of Socket, $T_s$ | Average Strength, lb. per lin. ft. | | Maximum Absorption, % | Limits of Permissible Variation in: | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Three-Edge-Bearing Method | Sand-Bearing Method | | Length, in. per ft. (−)[b] | Internal Diameter, in. Spigot (±)[b] | Internal Diameter, in. Socket, (±)[b] | Depth of Socket, in. (−)[b] | Thickness of Barrel, in. (−)[b] |
| 4 | 2, 2½, 3 | 6 | 1½ | 1:20 | 9/16 | The thickness of the socket ¼ in. from its outer end shall be not less than ¾ of the thickness of the barrel of the pipe. | 1000 | 1500 | 8 | ¼ | ⅛ | ⅛ | ⅛ | 1/16 |
| 6 | 2, 2½, 3 | 8¼ | 2 | 1:20 | ⅝ | | 1100 | 1650 | 8 | ¼ | 3/16 | 3/16 | ¼ | 1/16 |
| 8 | 2, 2½, 3, 4 | 10¾ | 2¼ | 1:20 | ¾ | | 1300 | 1950 | 8 | ¼ | ¼ | ¼ | ¼ | 1/16 |
| 10 | 2, 2½, 3, 4 | 13 | 2½ | 1:20 | ⅞ | | 1400 | 2100 | 8 | ¼ | ¼ | ¼ | ¼ | 1/16 |
| 12 | 2, 2½, 3, 4 | 15¼ | 2½ | 1:20 | 1 | | 1500 | 2250 | 8 | ¼ | ¼ | ¼ | ¼ | 1/16 |
| 15 | 2, 2½, 3, 4 | 18¾ | 2½ | 1:20 | 1¼ | | 1750 | 2620 | 8 | ¼ | ¼ | ¼ | ¼ | 3/32 |
| 18 | 2, 2½, 3, 4 | 22¼ | 2¾ | 1:20 | 1½ | | 2000 | 3000 | 8 | ¼ | ¼ | ¼ | ¼ | 3/32 |
| 21 | 2, 2½, 3, 4 | 26 | 2¾ | 1:20 | 1¾ | | 2200 | 3300 | 8 | ¼ | 5/16 | 5/16 | ¼ | ⅛ |
| 24 | 2, 2½, 3, 4 | 29½ | 3 | 1:20 | 2⅛ | | 2400 | 3600 | 8 | ⅜ | 5/16 | 5/16 | ¼ | ⅛ |

[a] When pipes are furnished having an increase in thickness over that given in last column, then the diameter of socket shall be increased by an amount equal to twice the increase of thickness of barrel.

[b] The minus sign (−) alone indicates that the plus variation is not limited; the plus-and-minus sign (±) indicates variation in both excess and deficiency in dimension.

*Note.* For weights and laying lengths, see Table 57.

## TABLE 54. REINFORCED-CONCRETE SEWER PIPE, A.S.T.M. SPEC. C-75-41

| Internal Diameter, in. | Strength Test Requirements, lb. per lin. ft. | | | | Minimum Design Requirements [a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Three-Edge-Bearing Method | | Sand-Bearing Method | | Concrete, 3000 psi. | | Concrete, 3500 psi. | | Concrete, 4000 psi. | |
| | Load to Produce a 0.01-in. Crack | Ultimate Load | Load to Produce a 0.01-in. Crack | Ultimate Load | Shell Thickness, in. | Total Steel Area, sq. in. per lin. ft. | Shell Thickness, in. | Total Steel Area, sq. in. per lin. ft. | Shell Thickness, in. | Total Steel Area, sq. in. per lin. ft. |
| 12 | 1,800 | 2,700 | 2,700 | 4,050 | 2 | 1 line 0.06 | 1¾ | 1 line 0.07 | ... | ..................... |
| 15 | 2,000 | 3,000 | 3,000 | 4,500 | 2¼ | 1 line 0.06 | 2 | 1 line 0.07 | ... | ..................... |
| 18 | 2,200 | 3,300 | 3,300 | 4,950 | 2½ | 1 line 0.06 | ... | ..................... | 2 | 1 line 0.07 |
| 21 | 2,400 | 3,600 | 3,600 | 5,400 | 2¾ | 1 line 0.06 | ... | ..................... | 2¼ | 1 line 0.07 |
| 24 | 2,400 | 3,600 | 3,600 | 5,400 | 3 | 1 line 0.06 | 2⅝ | 1 line 0.08 | 2½ | 1 line 0.09 |
| 27 | 2,550 | 3,800 | 3,800 | 5,700 | 3 | 1 line 0.07 | 2¾ | 1 line 0.10 | 2⅝ | 1 line 0.12 |
| 30 | 2,700 | 4,050 | 4,050 | 6,100 | 3½ | 1 line 0.09 | 3 | 1 line 0.12 | 2¾ | 1 line 0.14 |
| 33 | 2,850 | 4,300 | 4,300 | 6,400 | 3¾ | 1 line 0.11 | 3¼ | 1 line 0.14 | 2¾ | 1 line 0.17 |
| 36 | 3,000 | 4,500 | 4,500 | 6,750 | 4 | 2 lines [b] totalling 0.14 | 3⅜ | 2 lines [b] totalling 0.20 | 3 | 2 lines [b] totalling 0.23 |
| 42 | 3,200 | 4,800 | 4,800 | 7,200 | 4½ | 2 lines [b] totalling 0.16 | 3¾ | 2 lines [b] totalling 0.23 | 3⅜ | 2 lines [b] totalling 0.27 |
| 48 | 3,400 | 5,100 | 5,100 | 7,650 | 5 | 2 lines [b] totalling 0.21 | 4¼ | 2 lines [b] totalling 0.27 | 3¾ | 2 lines [b] totalling 0.32 |
| 54 | 3,700 | 5,550 | 5,550 | 8,300 | 5½ | 2 lines [b] totalling 0.25 | 4⅝ | 2 lines [b] totalling 0.32 | 4¼ | 2 lines [b] totalling 0.38 |
| 60 | 4,000 | 6,000 | 6,000 | 9,000 | 6 | 2 lines [b] totalling 0.29 | 5 | 2 lines [b] totalling 0.38 | 4½ | 2 lines [b] totalling 0.44 |
| 66 | 4,250 | 6,350 | 6,350 | 9,550 | 6½ | 2 lines [b] totalling 0.32 | 5⅜ | 2 lines [b] totalling 0.44 | 4¾ | 2 lines [b] totalling 0.47 |
| 72 | 4,500 | 6,750 | 6,750 | 10,100 | 7 | 2 lines [b] totalling 0.36 | 5¾ | 2 lines [b] totalling 0.47 | 5 | 2 lines [b] totalling 0.55 |
| 78 | ..... | ..... | ..... | ...... | 7½ | 2 lines [b] totalling 0.40 | ... | ..................... | ... | ..................... |
| 84 | ..... | ..... | ..... | ...... | 8 | 2 lines [b] totalling 0.43 | ... | ..................... | ... | ..................... |
| 90 | ..... | ..... | ..... | ...... | 8 | 2 lines [b] totalling 0.49 | ... | ..................... | ... | ..................... |
| 96 | ..... | ..... | ..... | ...... | 8½ | 2 lines [b] totalling 0.57 | ... | ..................... | ... | ..................... |
| 108 | ..... | ..... | ..... | ...... | 9 | 2 lines [b] totalling 0.67 | ... | ..................... | .. | ..................... |

*a* The distance from the center line of the reinforcement to the nearest surface of the concrete has been assumed in the design tables as 1 in.
*b* Where two lines of steel are specified, a single line placed elliptically may be used, and the area of this shall be at least 50% of the total steel area specified in the design table. *Note.* For weights and laying lengths, see Table 57.

TABLE 55. STANDARD STRENGTH REINFORCED-CONCRETE CULVERT PIPE, A.S.T.M. SPEC. C-76-41

| Internal Diameter of Pipe, in. | Concrete, 3,500 psi. | | | | Concrete, 4,500 psi. | | | | Strength Test Requirements, lb. per lin. ft. of pipe | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum Shell Thickness, in. | Minimum Reinforcement,[a] sq. in. per lin. ft. of pipe barrel [b] | | Weight per Lin. Ft., lb.[c] | Minimum Shell Thickness, in. | Minimum Reinforcement,[a] sq. in. per lin. ft. of pipe barrel [b] | | Weight per Lin. Ft., lb.[c] | Three-Edge-Bearing Method [d] | |
| | | Circular Reinforcement in Circular Pipe | Elliptical Reinforcement in Circular Pipe and Circular Reinforcement in Elliptical Pipe | | | Circular Reinforcement in Circular Pipe | Elliptical Reinforcement in Circular Pipe and Circular Reinforcement in Elliptical Pipe | | Load to Produce a 0.01-in. Crack | Ultimate Load |
| 12 | 2 | 1 line 0.07 | ......... | 88 | 1¾ | 1 line 0.08 | ......... | 75 | 2,250 | 3,500 |
| 15 | 2¼ | 1 line 0.09 | ......... | 125 | 2 | 1 line 0.11 | ......... | 110 | 2,625 | 4,065 |
| 18 | 2½ | 1 line 0.12 | 1 line 0.10 | 160 | 2 | 1 line 0.14 | ......... | 140 | 3,000 | 4,500 |
| 24 | 3 | 1 line 0.17 | 1 line 0.13 | 260 | 2½ | 1 line 0.20 | 1 line 0.17 | 225 | 3,000 | 5,000 |
| 30 | 3½ | 1 line 0.22 | 1 line 0.17 | 370 | 3 | 1 line 0.28 | 1 line 0.21 | 315 | 3,375 | 5,750 |
| 36 | 4 | 2 lines, each 0.18 | 1 line 0.18 | 520 | 3⅜ | 2 lines, each 0.22 | 1 line 0.22 | 450 | 4,050 | 6,600 |
| 42 | 4½ | 2 lines, each 0.21 | 1 line 0.21 | 680 | 3¾ | 2 lines, each 0.25 | 1 line 0.25 | 560 | 4,725 | 7,350 |
| 48 | 5 | 2 lines, each 0.25 | 1 line 0.25 | 850 | 4¼ | 2 lines, each 0.31 | 1 line 0.31 | 720 | 5,400 | 8,000 |
| 54 | 5½ | 2 lines, each 0.30 | 1 line 0.30 | 1,050 | 4⅝ | 2 lines, each 0.37 | 1 line 0.37 | 880 | 5,850 | 9,000 |
| 60 | 6 | 2 lines, each 0.33 | 1 line 0.33 | 1,280 | 5 | 2 lines, each 0.41 | 1 line 0.41 | 1,060 | 6,000 | 10,000 |
| 66 | 6½ | 2 lines, each 0.37 | 1 line 0.37 | 1,480 | 5½ | 2 lines, each 0.45 | 1 line 0.45 | ..... | 6,300 | 11,000 |
| 72 | 7 | 2 lines, each 0.40 | 1 line 0.40 | 1,835 | 6 | 2 lines, each 0.48 | 1 line 0.48 | ..... | 6,600 | 12,000 |
| 78 | 7½ | 2 lines, each 0.43 | 1 line 0.43 | 2,150 | 6½ | 2 lines, each 0.51 | 1 line 0.51 | ..... | ..... | ..... |
| 84 | 8 | 2 lines, each 0.46 | 1 line 0.46 | 2,300 | 7 | 2 lines, each 0.54 | 1 line 0.54 | ..... | ..... | ..... |
| 90 | 8 | 2 lines, each 0.56 | 1 line 0.56 | 2,600 | ... | .............. | ......... | ..... | ..... | ..... |
| 96 | 8½ | 2 lines, each 0.60 | 1 line 0.60 | 2,750 | ... | .............. | ......... | ..... | ..... | ..... |
| 102 | 8½ | 2 lines, each 0.72 | 1 line 0.72 | 3,050 | ... | .............. | ......... | ..... | ..... | ..... |
| 108 | 9 | 2 lines, each 0.78 | 1 line 0.78 | 3,450 | ... | .............. | ......... | ..... | ..... | ..... |

[a] The distance from the center line of the reinforcement to the nearest surface of the concrete has been assumed in the design tables as 1¼ in. for pipe with a shell 2½ in. or more in thickness.
[b] For 2 lines or elliptical reinf., provide 1-in. cover.
[c] *From Universal Concrete Pipe Co. for tongue and groove pipe.*
[d] Test loads for sand-bearing tests shall be 1½ times those specified in this table for the three-edge-bearing tests.

## TABLE 56. EXTRA-STRENGTH REINFORCED-CONCRETE CULVERT PIPE, A.S.T.M. SPEC. C-76-41

| Internal Diameter of Pipe, in. | Concrete, 4500 psi. | | | Strength Test Requirements, lb. per lin. ft. of pipe | | Weight per Lin. Ft. in Lb.[d] |
|---|---|---|---|---|---|---|
| | Minimum Shell Thickness, in. | Minimum Reinforcement,[a] sq. in. per lin. ft. of pipe barrel[b] | | Three-Edge-Bearing Method[c] | | |
| | | Circular Reinforcement in Circular Pipe | Elliptical Reinforcement in Circular Pipe and Circular Reinforcement in Elliptical Pipe | Load to Produce a 0.01-in. Crack | Ultimate Load | |
| 24 | 3 | 1 line 0.26 | 1 line 0.20 | 4,000 | 6,000 | 260 |
| 30 | 3½ | 1 line 0.31 | 1 line 0.24 | 5,000 | 7,500 | 370 |
| 36 | 4 | 2 lines, each 0.28 | 1 line 0.28 | 6,000 | 9,000 | 520 |
| 42 | 4½ | 2 lines, each 0.33 | 1 line 0.33 | 7,000 | 10,500 | 680 |
| 48 | 5 | 2 lines, each 0.38 | 1 line 0.38 | 8,000 | 12,000 | 850 |
| 54 | 5½ | 2 lines, each 0.44 | 1 line 0.44 | 9,000 | 13,500 | 1,050 |
| 60 | 6 | 2 lines, each 0.50 | 1 line 0.50 | 9,000 | 15,000 | 1,280 |
| 66 | 6½ | 2 lines, each 0.56 | 1 line 0.56 | 9,500 | 16,500 | 1,480 |
| 72 | 7 | 2 lines, each 0.60 | 1 line 0.60 | 9,900 | 18,000 | 1,835 |
| 78 | 7½ | 2 lines, each 0.65 | 1 line 0.65 | ..... | ...... | 2,150 |
| 84 | 8 | 2 lines, each 0.72 | 1 line 0.72 | ..... | ...... | 2,300 |
| 90 | 8 | 2 lines, each 0.84 | 1 line 0.84 | ..... | ...... | 2,600 |
| 96 | 8½ | 2 lines, each 0.90 | 1 line 0.90 | ..... | ...... | 2,750 |
| 102 | 8½ | 2 lines, each 1.08 | 1 line 1.08 | ..... | ...... | 3,050 |
| 108 | 9 | 2 lines, each 1.17 | 1 line 1.17 | ..... | ...... | 3,450 |

[a] The distance from the center line of the reinforcement to the nearest surface of the concrete has been assumed in the design tables as 1¼ in. for pipe with a shell 2½ in. or more in thickness.

[b] For 2 lines or elliptical reinforcement provide 1-in. cover.

[c] Test loads for sand-bearing tests shall be 1½ times those specified in this table for the three-edge-bearing tests.

[d] *From Universal Concrete Pipe Co. for tongue and groove pipe.*

## TABLE 57. CONCRETE PIPE, WEIGHTS AND LAYING LENGTHS *

### Non-Reinforced Sewer Pipe
A.S.T.M. C-14-41

| Inside Diameter, in. | Length, ft. | Wall Thickness, in. | Weight per Lineal Foot, lb. |
|---|---|---|---|
| 6 | 3 | 1 | 25 |
| 8 | 3 | 1 | 35 |
| 10 | 3 | 1⅛ | 48 |
| 12 | 4 | 1¼ | 60 |
| 15 | 4 | 1½ | 90 |
| 18 | 4 | 1¾ | 120 |
| 21 | 4 | 2 | 190 |
| 24 | 4 | 2¼ | 225 |
| 24 | 4 | 2⅝ | 255 |

### Bell-End Extra-Strength Culvert Pipe C-76-41

| Inside Diameter, in. | Length, ft. | Wall Thickness, in. | Weight per Lineal Foot, lb. |
|---|---|---|---|
| 12 | 4 | 2 | 100 |
| 15 | 4 | 2¼ | 150 |
| 18 | 4 | 2½ | 205 |
| 21 | 4 | 2¾ | 255 |
| 24 | 4 | 3 | 320 |
| 30 | 4 | 3½ | 470 |
| 36 | 4 | 4 | 600 |
| 42 | 4 | 4½ | 750 |
| 48 | 4 | 5 | 1000 |

### Machine Bell and Spigot Reinforced-Concrete Pipe
C-75-41 and C-76-41

| | | | |
|---|---|---|---|
| 12 | 4 | 1¾ | 90 |
| 15 | 4 | 2 | 125 |
| 18 | 4 | 2¼ | 160 |
| 21 | 4 | 2⅜ | 205 |
| 24 | 4 | 2⅝ | 260 |
| 27 | 4 | 2¾ | 300 |
| 30 | 4 | 3 | 370 |
| 36 | 4 | 3½ | 510 |
| 42 | 4 | 3¾ | 660 |
| 48 | 4 | 4¼ | 835 |

### Tongue and Groove Reinforced-Concrete Pipe
C-75-41 3500 psi Concrete
C-76-41 Table 55 4500 psi Concrete

| | | | |
|---|---|---|---|
| 12 | 4 | 1¾ | 75 |
| 15 | 4 | 2 | 110 |
| 18 | 4 | 2¼ | 140 |
| 24 | 4 | 2⅝ | 225 |
| 30 | 4 | 3 | 315 |
| 36 | 4 | 3½ | 450 |
| 42 | 4 | 3¾ | 560 |
| 48 | 4 | 4¼ | 720 |
| 54 | 4 | 4⅝ | 880 |
| 60 | 4 | 5 | 1060 |

### Tongue and Groove Reinforced-Concrete Pipe
C-75-41 3000 psi Concrete
C-76-41 Table 55 3500 psi Concrete
C-76-41 Table 56 4500 psi Concrete

| | | | |
|---|---|---|---|
| 6 | 3 | 1¾ | 48 |
| 8 | 4 | 2 | 65 |
| 10 | 4 | 2 | 80 |
| 12 | 4 | 2 | 88 |
| 15 | 4 | 2¼ | 125 |
| 18 | 4 | 2½ | 160 |
| 21 | 4 | 2¾ | 205 |
| 24 | 4 | 3 | 260 |
| 27 | 4 | 3¼ | 310 |
| 30 | 4 | 3½ | 370 |
| 33 | 4 | 3¾ | 450 |
| 36 | 4 | 4 | 520 |
| 39 | 4 | 4¼ | 600 |
| 42 | 4 | 4½ | 680 |
| 45 | 4 | 4¾ | 760 |
| 48 | 4 | 5 | 850 |
| 54 | 4 | 5½ | 1050 |
| 60 | 4 | 6 | 1280 |
| 66 | 4′, 5′, 6′ | 6½ | 1480 |
| 72 | 4′, 5′, 6′ | 7 | 1835 |
| 78 | 4′, 5′, 6′ | 7½ | 2150 |
| 84 | 4′, 5′, 6′ | 8 | 2300 |
| 90 | 4′, 5′, 6′ | 8 | 2600 |
| 96 | 4′, 5′, 6′ | 8½ | 2750 |
| 102 | 4′, 5′, 6′ | 8½ | 3050 |
| 108 | 4′, 5′, 6′ | 9 | 3450 |

* *From Universal Concrete Pipe Co.*

## TABLE 58. AMERICAN WATER WORKS ASSOCIATION STANDARD CAST-IRON PIPE *

| Nominal Inside Diameter, in. | Class A 100-Ft. Head 43 Lb. Pressure | | Class B 200-Ft. Head 86 Lb. Pressure | | Class C 300-Ft. Head 130 Lb. Pressure | | Class D 400-Ft. Head 173 Lb. Pressure | |
|---|---|---|---|---|---|---|---|---|
| | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. |
| 3 | 0.39 | 14.5 | 0.42 | 16.2 | 0.45 | 17.1 | 0.48 | 18.0 |
| 4 | 0.42 | 20.0 | 0.45 | 21.7 | 0.48 | 23.3 | 0.52 | 25.0 |
| 6 | 0.44 | 30.8 | 0.48 | 33.3 | 0.51 | 35.8 | 0.55 | 38.3 |
| 8 | 0.46 | 42.9 | 0.51 | 47.5 | 0.56 | 52.1 | 0.60 | 55.8 |
| 10 | 0.50 | 57.1 | 0.57 | 63.8 | 0.62 | 70.8 | 0.68 | 76.7 |
| 12 | 0.54 | 72.5 | 0.62 | 82.1 | 0.68 | 91.7 | 0.75 | 100.0 |
| 14 | 0.57 | 89.6 | 0.66 | 102.5 | 0.74 | 116.7 | 0.82 | 129.2 |
| 16 | 0.60 | 108.3 | 0.70 | 125.0 | 0.80 | 143.8 | 0.89 | 158.3 |
| 18 | 0.64 | 129.2 | 0.75 | 150.0 | 0.87 | 175.0 | 0.96 | 191.7 |
| 20 | 0.67 | 150.0 | 0.80 | 175.0 | 0.92 | 208.3 | 1.03 | 229.2 |
| 24 | 0.76 | 204.2 | 0.89 | 233.3 | 1.04 | 279.2 | 1.16 | 306.7 |
| 30 | 0.88 | 291.7 | 1.03 | 333.3 | 1.20 | 400.0 | 1.37 | 450.0 |
| 36 | 0.99 | 391.7 | 1.15 | 454.2 | 1.36 | 545.8 | 1.58 | 625.0 |
| 42 | 1.10 | 512.5 | 1.28 | 591.7 | 1.54 | 716.7 | 1.78 | 825.0 |

* *From Handbook of Cast Iron Pipe by C. I. Pipe Research Assn.*

Water hammer of ordinary intensity allowed for in the above table. Weights based on 12-ft. length.

## TABLE 59. FEDERAL SPECIFICATIONS, WW-P-421 STANDARD

| Nominal Inside Diameter, in. | 100-lb. Class † or Max. Working Pressure | | 150-lb. Class ‡ or Max. Working Pressure | | 200-lb. Class † or Max. Working Pressure | | 250-lb. Class ‡ or Max. Working Pressure | |
|---|---|---|---|---|---|---|---|---|
| | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. | Thickness, in. | Approximate Weight per Ft., lb. |
| 3 | | | 0.33 | 12.5 | | | 0.36 | 13.8 |
| 4 | | | 0.34 | 16.1 | | | 0.38 | 18.1 |
| 6 | | | 0.37 | 25.7 | | | 0.43 | 28.7 |
| 8 | | | 0.42 | 38.6 | 0.46 | 41.6 | 0.50 | 44.6 |
| 10 | | | 0.47 | 52.2 | 0.52 | 57.2 | 0.57 | 62.3 |
| 12 | | | 0.50 | 66.1 | 0.57 | 74.1 | 0.62 | 81.1 |
| 14 | 0.48 | 74.9 | 0.55 | 86.9 | 0.62 | 97.0 | 0.69 | 108.0 |
| 16 | 0.52 | 92.1 | 0.60 | 108.1 | 0.68 | 121.6 | 0.75 | 133.6 |
| 18 | 0.56 | 111.4 | 0.65 | 130.4 | 0.74 | 147.9 | 0.83 | 164.9 |
| 20 | 0.58 | 129.0 | 0.68 | 152.0 | 0.78 | 173.6 | 0.88 | 193.6 |
| 24 | 0.64 | 169.9 | 0.76 | 202.9 | 0.88 | 233.1 | 1.00 | 262.1 |

† *From American Cast Iron Pipe Co.* ‡ *From Federal Specifications WW-P-421.*

Water hammer of ordinary intensity allowed for in the above table. Weights based on 16-ft. length. 100 lb. Class—weights for Class B fittings; 150 lb., 200 lb., 250 lb. Classes—weights for Class D fittings.

## TABLE 60. STANDARD THICKNESSES AND WEIGHTS OF CAST-IRON PIT CAST PIPE *

| Size Inches | Class 50 | | | Class 100 | | | Class 150 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 50 Lb. Pressure | | | 100 Lb. Pressure | | | 150 Lb. Pressure | | |
| | 115 Feet Head | | | 231 Feet Head | | | 346 Feet Head | | |
| | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length |
| 3 | .37 | 14.2 | 170 | .37 | 14.2 | 170 | .37 | 14.2 | 170 |
| 4 | .40 | 19.2 | 230 | .40 | 19.2 | 230 | .40 | 19.2 | 230 |
| 6 | .43 | 30.0 | 360 | .43 | 30.0 | 360 | .43 | 30.0 | 360 |
| 8 | .46 | 42.9 | 515 | .46 | 42.9 | 515 | .46 | 42.9 | 515 |
| 10 | .50 | 57.1 | 685 | .50 | 57.1 | 685 | .54 | 60.8 | 730 |
| 12 | .54 | 73.3 | 880 | .54 | 73.3 | 880 | .58 | 77.9 | 935 |
| 14 | .54 | 85.4 | 1,025 | .58 | 91.3 | 1,095 | .63 | 100.8 | 1,210 |
| 16 | .58 | 105.4 | 1,265 | .63 | 113.3 | 1,360 | .68 | 125.0 | 1,500 |
| 18 | .63 | 127.9 | 1,535 | .68 | 136.7 | 1,640 | .73 | 150.4 | 1,805 |
| 20 | .66 | 148.8 | 1,785 | .71 | 158.8 | 1,905 | .83 | 188.8 | 2,265 |
| 24 | .74 | 198.8 | 2,385 | .80 | 212.9 | 2,555 | .93 | 252.5 | 3,030 |
| 30 | .87 | 288.3 | 3,460 | .94 | 311.3 | 3,735 | 1.10 | 367.1 | 4,405 |
| 36 | .97 | 384.2 | 4,610 | 1.05 | 420.8 | 5,050 | 1.22 | 491.3 | 5,895 |
| 42 | 1.07 | 497.5 | 5,970 | 1.25 | 579.2 | 6,950 | 1.35 | 637.9 | 7,655 |
| 48 | 1.18 | 625.8 | 7,510 | 1.37 | 726.3 | 8,715 | 1.48 | 799.6 | 9,595 |
| 54 | 1.30 | 777.1 | 9,325 | 1.51 | 906.3 | 10,875 | 1.63 | 997.1 | 11,965 |
| 60 | 1.39 | 922.5 | 11,070 | 1.62 | 1,077.1 | 12,925 | 1.89 | 1,270.9 | 15,250 |

| Size Inches | Class 200 | | | Class 250 | | | Class 300 | | | Class 350 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 200 Lb. Pressure | | | 250 Lb. Pressure | | | 300 Lb. Pressure | | | 350 Lb. Pressure | | |
| | 462 Feet Head | | | 577 Feet Head | | | 693 Feet Head | | | 808 Feet Head | | |
| | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length | Thickness, inches | Wt. Based on 12 Ft. Lgh.† Avg. Per Foot | Wt. Based on 12 Ft. Lgh.† Per Length |
| 3 | .37 | 14.2 | 170 | .37 | 14.2 | 170 | .37 | 14.2 | 170 | .37 | 14.2 | 170 |
| 4 | .40 | 19.2 | 230 | .40 | 19.2 | 230 | .40 | 19.2 | 230 | .40 | 19.2 | 230 |
| 6 | .43 | 30.0 | 360 | .43 | 30.0 | 360 | .46 | 31.7 | 380 | .50 | 34.2 | 410 |
| 8 | .46 | 42.9 | 515 | .50 | 45.8 | 550 | .54 | 49.2 | 590 | .58 | 53.8 | 645 |
| 10 | .58 | 64.6 | 775 | .63 | 72.1 | 865 | .68 | 77.1 | 925 | .73 | 81.7 | 980 |
| 12 | .63 | 83.8 | 1,005 | .68 | 92.1 | 1,105 | .73 | 97.9 | 1,175 | .79 | 105.0 | 1,260 |
| 14 | .68 | 107.9 | 1,295 | .79 | 123.3 | 1,480 | .85 | 131.7 | 1,580 | .92 | 148.3 | 1,780 |
| 16 | .79 | 142.5 | 1,710 | .85 | 152.1 | 1,825 | .92 | 162.9 | 1,955 | .99 | 181.7 | 2,180 |
| 18 | .85 | 172.1 | 2,065 | .92 | 184.2 | 2,210 | .99 | 196.7 | 2,360 | 1.07 | 220.8 | 2,650 |
| 20 | .90 | 202.5 | 2,430 | .97 | 216.7 | 2,600 | 1.05 | 232.1 | 2,785 | 1.22 | 277.1 | 3,325 |
| 24 | 1.00 | 269.2 | 3,230 | 1.08 | 288.3 | 3,460 | 1.26 | 346.2 | 4,155 | 1.36 | 370.0 | 4,440 |
| 30 | 1.19 | 402.9 | 4,835 | 1.39 | 462.1 | 5,545 | 1.50 | 511.3 | 6,135 | 1.62 | 557.9 | 6,695 |
| 36 | 1.43 | 578.3 | 6,940 | 1.54 | 617.1 | 7,405 | 1.79 | 727.9 | 8,735 | 1.93 | 794.2 | 9,530 |
| 42 | 1.58 | 749.2 | 8,990 | 1.71 | 802.9 | 9,635 | | | | | | |
| 48 | 1.73 | 940.0 | 11,280 | 2.02 | 1,077.1 | 12,925 | | | | | | |
| 54 | 1.90 | 1,168.8 | 14,025 | 2.21 | 1,333.8 | 16,005 | | | | | | |
| 60 | 2.20 | 1,488.3 | 17,860 | 2.38 | 1,594.6 | 19,135 | | | | | | |

* *From American Standard Assn., Spec. A21.2–1939.*
† Including bell and spigot bead. Calculated weight of pipe rounded off to nearest 5 pounds.

*Note.* These weights are for pipe laid without blocks, on flat bottom trench, with tamped backfill, under 5 feet of cover.

TABLE 61. APPROXIMATE QUANTITIES OF MATERIALS USED PER JOINT FOR WATER SERVICE *

| Nominal Diameter, In. | Pounds of Joint Compound 2½″ Joint Depth † | Pounds of Hemp per Joint | Pounds of Lead in Joint 2″ Deep | Pounds of Lead in Joint 2¼″ Deep | Pounds of Lead in Joint 2½″ Deep |
|---|---|---|---|---|---|
| 3 | | 0.18 | 6.00 | 6.50 | 7.00 |
| 4 | 2.00 | 0.21 | 7.50 | 8.00 | 8.75 |
| 6 | 3.00 | 0.31 | 10.25 | 11.25 | 12.25 |
| 8 | 4.00 | 0.44 | 13.25 | 14.50 | 15.75 |
| 10 | 5.00 | 0.53 | 16.00 | 17.50 | 19.00 |
| 12 | 6.00 | 0.61 | 19.00 | 20.50 | 22.50 |
| 14 | 7.00 | 0.81 | 22.00 | 24.00 | 26.00 |
| 16 | 8.25 | 0.94 | 30.00 | 33.00 | 35.75 |
| 18 | 9.25 | 1.00 | 33.80 | 36.90 | 40.00 |
| 20 | 10.50 | 1.25 | 37.00 | 40.50 | 44.00 |
| 24 | 13.00 | 1.50 | 44.00 | 48.00 | 52.50 |

* *Adapted from U. S. Pipe and Foundry Co.*

† Approximate only; will vary with kind of material used.

*Note.* Weight of lead is based on std. wt. = 0.41 lb. per cu. in. This weight may vary 15% depending on purity.

## TABLE 62. STEEL PIPE, A.S.T.M. A53-44, WEIGHTS AND DIMENSIONS

| Pipe Diameter Nominal Sizes, in. | Outside Diameter, in. | Number of Threads per inch | Standard-Weight Pipe | | | | Extra-Strong Pipe | | | | Double Extra-Strong Pipe | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Schedule 30 | | Schedule 40 | | Schedule 60 | | Schedule 80 | | | |
| | | | Thickness, in. | Wt. of Pipe, lb. per ft., Threaded and with Couplings | Thickness, in. | Wt. of Pipe, lb. per ft., Threaded and with Couplings | Thickness, in. | Weight of Pipe, lb. per ft., Plain Ends | Thickness, in. | Weight of Pipe, lb. per ft., Plain Ends | Thickness, in. | Weight of Pipe, lb. per ft., Plain Ends |
| 2 | 2.375 | 11½ | | | 0.154 | 3.68 | | | 0.218 | 5.02 | 0.436 | 9.03 |
| 4 | 4.500 | 8 | | | 0.237 | 10.89 | | | 0.337 | 14.98 | 0.674 | 27.54 |
| 6 | 6.625 | 8 | | | 0.280 | 19.18 | | | 0.432 | 28.57 | 0.864 | 53.16 |
| 8 | 8.625 | 8 | 0.277 | 25.00 | 0.322 | 28.81 | | | 0.500 | 43.39 | 0.875 | 72.42 |
| 10 | 10.750 | 8 | 0.307 | 35.00 | 0.365 | 41.13 | 0.500 | 54.74 | | | | |
| 12 | 12.750 | 8 | 0.330 | 45.00 | 0.375 | 50.71 | 0.500 | 65.41 | | | | |

Sizes larger than 12 in. are specified by their outside diameter, O.D., and thickness. These larger sizes are furnished with plain ends, unless otherwise specified. The weights for O.D. pipe are given by manufacturers' published standards although it is possible to calculate the theoretical weights for any given size and wall thickness on the basis of 1 cu. in. of steel weighing 0.2833 lb.

The table does not give complete list of sizes less than 6 in.

TABLE 63. CEMENT-ASBESTOS WATER PIPE (TRANSITE)

| Pipe Size,* in. | Class 50 | | Class 100 | | Class 150 | | Class 200 | |
|---|---|---|---|---|---|---|---|---|
| | Shell Thickness, in. | Weight per Lin. Ft., lb. | Shell Thickness, in. | Weight per Lin. Ft., lb. | Shell Thickness, in. | Weight per Lin. Ft., lb. | Shell Thickness, in. | Weight per Lin. Ft., lb. |
| 3 | 0.33 | 3.6 | 0.35 | 3.8 | 0.44 | 4.6 | 0.60 | 6.6 |
| 3½ | 0.33 | 4.2 | 0.35 | 4.4 | 0.45 | 5.4 | 0.60 | 7.5 |
| 4 | 0.33 | 4.7 | 0.35 | 5.0 | 0.45 | 6.0 | 0.60 | 8.4 |
| 4½ | 0.34 | 5.4 | 0.36 | 5.6 | 0.48 | 7.3 | 0.64 | 10.0 |
| 5 | 0.35 | 6.2 | 0.37 | 6.4 | 0.51 | 8.6 | 0.68 | 11.8 |
| 6 | 0.36 | 7.6 | 0.38 | 7.8 | 0.55 | 10.7 | 0.75 | 15.4 |
| 7 | 0.38 | 9.3 | 0.41 | 9.8 | 0.61 | 14.1 | 0.82 | 19.5 |
| 8 | 0.42 | 11.7 | 0.44 | 11.9 | 0.65 | 16.8 | 0.88 | 23.7 |
| 10 | 0.44 | 15.2 | 0.59 | 19.8 | 0.85 | 28.0 | 1.10 | 37.0 |
| 12 | 0.48 | 19.8 | 0.68 | 27.6 | 0.98 | 38.6 | 1.24 | 49.6 |
| 14 | 0.52 | 24.8 | 0.78 | 36.6 | 1.13 | 51.6 | 1.44 | 67.0 |
| 16 | 0.56 | 30.6 | 0.88 | 47.0 | 1.25 | 65.0 | 1.65 | 87.8 |
| 18 | 0.59 | 35.9 | 0.97 | 58.2 | 1.39 | 81.2 | 1.87 | 112.0 |
| 20 | 0.63 | 42.5 | 1.07 | 71.2 | 1.53 | 99.5 | 2.09 | 139.5 |
| 24 | 0.69 | 55.5 | 1.25 | 99.3 | 1.82 | 141.5 | 2.48 | 199.0 |
| 30 | 0.90 | 89.2 | 1.54 | 150.6 | 2.29 | 221.0 | 3.12 | 310.0 |
| 36 | 1.09 | 126.3 | 1.83 | 211.0 | 2.80 | 318.0 | 3.74 | 435.0 |

* Pipe size is inside diameter except sizes 4, 6, and 8 in. in Class 150 which are 3.95, 5.85, and 7.85 in., respectively.

Class of pipe is same as allowable working pressure in pounds per square inch. Furnished in straight lengths only, standard length = 13 ft.

## CHECK LIST FOR INSPECTORS

## PIPE LAYING

**Inspectors' Equipment**

Complete set of plans, specifications, and approved shop drawings.

Calipers.

6-ft. rule, 50-ft. tape and mason's level.

Plumb bob and line.

**Procedure in Inspection**

Check all pipe delivered for conformity with specification requirements of size, thickness, and reinforcement. Check pipe thickness with calipers and compare with tables, pp. 166–179.

Check all pipe and fittings for cracks or other defects before laying.

When concrete pipe is not inspected at the plant, have contractor cut into 5% of pipe delivered to job in order to check size and number of lines of reinforcing for verification of specification requirements.

Accept no elliptically reinforced pipe unless top is properly marked on outside of pipe. When installing such pipe, require exact centering of each piece.

Report to superior any unsatisfactory subgrade condition which may require special treatment such as removal of unsatisfactory material, consolidation of subgrade with stone or gravel, blocking, reinforced-concrete cradle, or pile support.

Permit no variation from type of bedding called for by plans or specifications except as directed. Remember that such change may require heavier pipe.

Where rock occurs, be sure earth, sand or gravel cushion is provided.

When laying bell and spigot or tongue and groove pipe, require spigot or tongue to be inserted to proper depth and center.

Always require asbestos-cement pipe to be laid with proper space between ends at each joint. See that bells are laid upgrade and excavation is carried on upgrade.

Require mechanical joints to be uniformly bolted, and welded joints to be thoroughly cleaned before welding begins.

Insist upon removal of water from trench where jointing is in progress, and require joints to be clean before lead or compound is poured.

Check each length as laid for size, strength, line, and grade.

Wherever bends or tees occur and in back of hydrants, require proper backing with concrete to prevent joints from opening under pressure.

Do not allow backfill to be placed over joints until pressure test has been made. If covered, require joint to be uncovered during test.

Require backfill to be placed exactly as specified.

Where pipe lines must pass through a fill as is common in the construction of treatment plants, see that pipes are supported by piers (or by other methods) resting on undisturbed soil.

Conduct tests for leakage in water mains and infiltration in sewer lines; see specifications.

Disinfection of pipes and tanks.

Do not place material under or around pipes which will have the effect of making a subdrain of trench.

______________________
Engineer

REPORT ON CLAY AND CONCRETE PIPE *

SHOP INSPECTION

Material ______________________

Project ______________________

Producer ______________________

Contractor ______________________ Date ______________

| Sample taken from | | | | Reported to |
|---|---|---|---|---|
| Quantity represented | | | | |
| Marks on sample | | | | |
| Sampled by | | | | |
| Date taken | | | | |
| Date rec'd at lab. | | | | |
| Job sample No. | | | | |
| Laboratory report No. | | | | |

| | | | | Required | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| Internal diameter of pipe, in. | | | | | |
| External diameter of pipe, in. | | | | | |
| Thickness of pipe, in. | | | | | |
| Internal diameter of bell, in. | | | | | |
| External diameter of bell, in. | | | | | |
| Thickness of bell, in. | | | | | |
| Total length of pipe, ft. | | | | | |
| Total length of bearing, ft. | | | | | |
| Load applied at first crack, lb. | | | | | |
| Load per lineal foot at first crack, lb. | | | | | |
| Maximum load applied, lb. | | | | | |
| Maximum load per lineal foot, lb. | | | | | |
| **ABSORPTION TEST** | | | | | |
| Weight after immersion, grams | | | | | |
| Weight after drying, grams | | | | | |
| Loss of weight | | | | | |
| Absorption, % | | | | | |
| **REINFORCEMENT** | | | | | |
| Number of lines of reinforcing | | | | | |
| Area of circular reinforcing per ft. of pipe, sq. in. | | | | | |
| Number of longitudinals | | | | | |
| Total area of longitudinals, sq. in. | | | | | |

Remarks:

The above tests do / do not fulfill A.S.T.M. Spec. ______________________.

______________________
Inspector

* *From Haller Engineering Associates, Inc.*

## INSPECTOR'S TIME RECORD

## TUTTLE, SEELYE, PLACE & RAYMOND

Week ending_____194__.
Name *Smith*

| Date | Description of Work Performed | Breakdown of Hours Worked on Each Job | | | | | | | Total Hours | Holidays, Vacation, and Sick Leave Allowed |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/1 | Adm. | 6 | | | | | | | 6 | |
| 2 | | 8 | | | | | | | 8 | |
| 3 | | 10 | | | | | | | 10 | |
| 4 | | 10 | | | | | | | 10 | |
| 5 | | | | | | | | | | |
| 6 | | 5 | | | | | | | 5 | |
| 7 | | 15 | | | | | | | 15 | |
| Total Hours | | 54 | | | | | | | 54 | |

Total Credit Hours *61*

| Breakdown in Hours Worked | |
|---|---|
| Job | Credit Hr |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| Holidays, Vacation, Sick Leave | |
| Total | |

Employee__________

Approved__________

PAYROLL AND EXPENSE RECORD
TUTTLE, SEELYE, PLACE & RAYMOND

Period ending ______________ Project ______________ Payroll No. ______________

| Income Tax Column | Name | Payroll | | | Tax Deductions | | | | Net Earnings | Expenses | | | | Net Earnings Plus Expenses | Check No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Credit Hours | Rate | Amount | Federal O.A. | Income Tax | | Total | | Travel | Subsistence | Misc. | Total | | |
| | Permanent Employees | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | | |
| | Temporary Employees | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | | |

Prepared by: ______________ Checked by: ______________
Title Title

INSPECTOR'S DAILY REPORT

AIRFIELD RUNWAYS

TUTTLE, SEELYE, PLACE & RAYMOND
ARCHITECT—ENGINEER
FORT DIX, NEW JERSEY

Directive No. ____________ Contract No. ____________ Report No. ____________
Prime contractor ______________________________ Date ____________
Subcontractor ______________________________________________
Weather ____________ Temp. 8 A.M. ________ 1 P.M. ________ 5 P.M. ________

| Items | Kind | Quantity | | | | Location |
|---|---|---|---|---|---|---|
| | | Units | Lin. Ft. | Sq. Yd. | Cu. Yd. | |
| *Roads*<br>Excavation | | | | | | |
| Borrow | | | | | | |
| Fine grading | | | | | | |
| Base | | | | | | |
| Top | | | | | | |
| Seal coat | | | | | | |
| Shoulders | | | | | | |
| Ditching | | | | | | |
| Culverts and drains | | | | | | |
| Foundation material | | | | | | |
| Water mains | | | | | | |
| Valves | | | | | | |
| Hydrants | | | | | | |
| Specials | | | | | | |
| Sanitary sewer mains | | | | | | |
| Manholes | | | | | | |
| Specials | | | | | | |
| Storm sewer mains | | | | | | |
| Manholes | | | | | | |
| Inlets | | | | | | |
| Head walls | | | | | | |

| Labor | Equipment | Inspector's Checking List | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sewers | | Water | | Roads | |
| | | Material | | Material | | Material | |
| | | Line | | Blocking | | Subgrade | |
| | | Grade | | Line | | Consolidation | |
| | | Joints | | Grade | | Surface | |
| | | Backfill | | Joints | | Culverts | |
| | | Manholes | | Backfill | | Head walls | |
| | | | | Valves | | Storm sewer | |
| Worked from | Worked from | | | Hydrant | | | |

Remarks: ________________________________________

________________________________

Inspector

## INSPECTOR'S DAILY REPORT — GENERAL CONSTRUCTION

Report No. ________ Sheet No. ________ Place ________________

Specification No. ____________________ Date ____________ 19__

Contract No. ________ For ________________________________

Contractor ____________________ Superintendent ____________________

Weather { A.M. ____________________ P.M. ____________________

Temperatures
Time of starting work—
A.M. ____________ ______ °F.
NOON ____________ ______ °F.
Time of stopping work—
P.M. ____________ ______ °F.

Tides (for all work affected thereby)
{ High ________ Elevation at ________ M.
Low ________ Elevation at ________ M.

| Contractor's Force Including Supervisors and Subcontractor's Forces | | | | | Work | | |
|---|---|---|---|---|---|---|---|
| No. | Trade | Hours | Rate | Amount Wages | Class | Quantity | Remarks |
| | | | | | | | |
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Material Received this Date

| Item | Delivered | Passed | Rejected | Item | Delivered | Passed | Rejected |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
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| | | | | | | | |
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| PLANT EQUIPMENT ON JOB | | GOVERNMENT UTILITIES FURNISHED | | | | | |
|---|---|---|---|---|---|---|---|
| Equipment | Hours Worked | No. | Appliance or Service | Hr. | Duty | Rate | Amt. |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Delays ________________________________________________________

Accidents ___________________________________________________

Defective work to be corrected later (enter in red) ________________________

Special instructions received or given ________________________________

Tests _________________________________________________________

Items started this date _________________________________________

Items completed this date _______________________________________

Contractor's plant

Items delivered _____________________________________________

Items removed ______________________________________________

Items out of commission (state time and cause) _________________________

Remarks: ____________________________________________________

______________________________, Inspector.

Instructions to inspectors. Make reports full and complete, and to include all work performed on contractor's plant. When the contractor, his chief engineer, general superintendent, or other responsible member of his organization visits the job, make a note, giving names, and also any instructions given by them to the superintendent on the job relative to the prosecution of the work. Note all accidents, delays, fires, etc., and give *your* opinion as to causes, and how the progress of the work is affected thereby.

* *From Navy Department—Bureau Yards and Docks.*

GENERAL CONTRACTOR'S DAILY REPORT

Date *10-4-45*
Weather *Clear*
Job ____________ Temperature ______

| | Mechanics | | Laborers | | Foreman | | |
|---|---|---|---|---|---|---|---|
| | No. | Time | No. | Time | No. | Time | |
| Superintendent | *1* | | | | | | |
| Watchman | | | | | | | |
| Timekeepers | *1* | | | | | | |
| Excavation | | | | | | | |
| Engineer | *1* | *7* | | | | | *Hoisting materials and taking down rubbish, etc.* |
| Forms | | | | | | | |
| Laborers | | | *17* | *119* | *1* | *8* | *Handling materials for ovens—7th floor*<br>*Chipping and cutting cols. and beams.* |
| Concrete | | | | | | | *Cleaning and taking down rubbish, etc. from 7th, 8th, and 9th floors.* |
| Cem. finish | | | | | | | *Loading truck with rubbish. Helping carpenters.* |
| Rein. steel | | | | | | | |
| Masonry | | | | | | | |
| Carpentry | *11* | *77* | | | | | *Shoring for center line for ovens.*<br>*Making up benches for lathers.*<br>*Building forms for cols.*<br>*Running power-saw and filing saws.*<br>*Framing haunches.*<br>*Shoring forms over ovens.* |

Equipment *Truck; hauling rubbish away.*

Subcontractors *Kalman. Watering Floors.*

| | |
|---|---|
| Excavation | Steel sash |
| Struct. steel | Calking |
| Misc. & orn. iron | Lathing |
| Cut stone | Plastering |
| Plumbing | Marble and tile |
| Heating | Floor covering |
| Electric | Weatherstripping |
| Waterproofing | Metal equipment |
| Hollow metal | Painting |
| Kalamein | Glazing |
| Rfg. & sheet metal | |

Remarks *Wreckers—Cutting arches on 9th floor. Cutting wood floor. 7th floor. Removing rubbish, etc., from 9th floor.*

Visitors

Signed ______________ Sheet No. ________
Supt.

## JOB POWER

In order to give the field engineer a general perspective of job power, the following is submitted.

Air compressors used in construction are of various types and sizes.

The most common type for the usual construction job is the portable type mounted on wheels for easy moving.

Compressor should be placed in a safe location to avoid injury but as close to operations as possible in order to avoid expensive labor and material in pipe lines, and to avoid decreased efficiency due to line losses, leaky joints, and actual breakage of line resulting from accident or carelessness.

Compressor capacity is rated on the actual cubic feet of air delivered at a designated pressure, usually 100 p.s.i.

The usual capacities for portable compressors are 105 cu. ft., 210 cu. ft., 315 cu. ft., 365 cu. ft., and 500 cu. ft.

There are many air tools for use with compressors; some of the more common are listed below:

Drills, jackhammers, wagon drills, drifters—for drilling holes in rock for use with explosives.

Breakers or busters—for breaking and chipping rock or loosening hard compact earth.

Air riveters (guns)—for driving rivets in steel bridge and building construction.

Plug drills—for plug and feather work, used generally in quarries for dimension stone such as granite, sandstone, and marble.

Air augers—for drilling holes in wood, in use on wooden piers, cofferdams, roof trusses, etc.

Bolt runners—for tightening bolts.

Tampers—to consolidate backfill.

Hoists, single and multiple drum—for use with derricks, mine scrapers, car haulage in industrial plants, etc.

Sheathing hammers—in trenches or cofferdams to drive wood sheathing, usually up to about 3 in. thick.

Air spades—for digging hard clay or other compact material.

Air vibrators—for concrete.

Pile hammers—for driving any type of pile.

Air saws, air clamps, etc.

The above tools use a varying amount of air, depending on size, mechanical condition of tool, etc.

For tools in general use on a construction job, such as a drill, breaker, tamper, and spades, a figure of 50 cu. ft. can be taken to estimate the compressor capacity required.

For example, a 210 cu. ft. compressor will operate four average size

drills, breakers, spades, or tampers, assuming that these tools are in fair mechanical condition.

The above figure is for practical field conditions.

Two or more compressors may be coupled together to increase the available amount of air. If this is done, the compressors should discharge into an air receiver or reservoir. This will increase efficiency, decrease wear on compressors, and insure an even flow of power to tools.

On any job it is good practice to have one spare tool for every four tools in use to avoid costly delays caused by mechanical failure.

Tools are expensive and should be well cared for; carelessness is an item that should not be on any report sheet.

Some attempts have been made to operate percussion tools (breakers) by gasoline or electricity, but this type of tool is not in general use as yet in the construction field.

Careful consideration should be given to weight of tool selected for various operations. For instance, a man can use a heavier, more powerful drill or breaker if he is drilling a down hole, i.e., a hole either vertical or on a slant away from him. But a much lighter tool should be provided for drilling or chipping a horizontal hole (breast hole), to avoid excessive fatigue. There is, however, a third leg or jack on the market which can be clamped to the drill or breaker which will relieve the operator of much of the weight of the tool and which adds considerably to the efficiency of the tool.

An air tool in operation is always cold owing to the expansion of the air out of the exhaust valve; hence, care must be taken to use a good grade of air oil for lubrication. One of the best of many ways to oil an air tool is by a line oiler. This is an oil reservoir holding about a pint of oil and can be set to provide oil drop by drop into the air line which is carried to the tool.

For several years manufacturers have provided a drill rod threaded on one end to receive a jack bit. This eliminates hand sharpening of steel on the job as the jack bit can be used until dull or until the gage is worn down, then it is simply unscrewed from the rod and replaced.

The gage of a bit is its width. As the drill rotates, the bit is worn down by the rock and gradually the bit becomes narrower until finally, in construction parlance, "the gage is gone."

The gage of a bit is of great importance. Drill rods usually provide for a depth of hole up to 10 ft. to 12 ft. or more by 2-ft. stages.

EXAMPLE.

GAGE

No. 1 or starter drill rod 2 ft.—Bit 2 in.
No. 2 drill rod 4 ft.—Bit 1¾ in.
No. 3 drill rod 6 ft.—Bit 1½ in.

Note that, on No. 1 bit, the gage is 2 in.

As the bit is worn or loses its gage, it is evident that No. 2 bit will not follow; that is, it will not seat at the bottom of the hole already drilled by No. 1. As a result, bit 2 will become fast in the hole resulting in loss of steel and time. The above bit sizes are arbitrary, but note that the gage for any following bit is ¼ in. smaller always.

Bits may be resharpened by special tools but always to a smaller gage; for example a 2-in. bit becomes 1¾ in., etc.

Bits are various shapes: X bits, cross bits + or six point or rose bits ⊛. The cross bit and six point are the more common. Although each shape has its strong supporters among rock men, in general it can be said that, in hard dense rock, the cross bit is superior, while in loosely stratified rock, the six point is superior. The six point bit is especially desirable in drilling concrete for demolition.

The use of goggles to protect the eyes is a wise precaution for men operating drills or breakers, and in enclosed places a simple dust mask can be provided to keep the nose and throat as free from dust as possible.

Electric tools such as saws, pumps, wood augers, vibrators, bolt runners, and drill presses have a place in construction. For many tools, electricity is more advantageous in that the primary power feeder is a distant power house and, after the feeder lines are run, power is available at the turn of a switch.

Gasoline- and diesel-fuel-driven motors are widely used as the primary power unit on all sizes of tools from the small compresser, table saws, pumps, vibrators, chain saws, electric generators, etc., to the giant locomotive.

# PART II

# SURVEYING

## TOPOGRAPHIC SURVEY

Traverse points should be selected with a view to economy of setups; e.g., so located that a maximum area can be seen by the instrument man. For accuracy the traverse should be run separately from the topography shots. For economy, where refined accuracy is not necessary, the traverse and the topography can be run simultaneously; i.e., the topography shots are taken as each traverse point is occupied.

Since stadia topography is normally plotted with a protractor, refinements greater than 15 minutes in the horizontal angle are not warranted. Considerable speed is attained when the horizontal angles are estimated to the nearest quarter degree and the vertical angles to the nearest minute.

### SAMPLE NOTES

STADIA TRAVERSE

All Horiz ∡s measured clockwise.

| Sta. Occ. | Sta. Obs. | Hor ∡ | Mag B | Rod Int. | Ver. ∡ | Hor Dist. |
|---|---|---|---|---|---|---|
| B | A | 0° | N 89° W | 5.44 | +2°40′ | 544′ |
| | C | 90° | N 1° E | 6.05 | −1°17′ | 606′ |
| | | | | | | |
| C | B | 0° | S 0° W | 6.07 | +1°16′ | 608′ |
| | D | 201°30′ | N 22° E | 6.95 | −1°27′ | 696′ |
| | | | | | | |
| D | C | 0° | S 21° W | 6.96 | +1°27′ | 697′ |
| | E | 221°0′ | N 62° E | 8.65 | −1°35′ | 865′ |
| | | | | | | |
| E | D | 0° | S 61° W | 8.64 | +1°35′ | 864′ |
| | F | 102°25′ | N 16° W | 10.21 | −3°25′ | 1018′ |
| | | | | | | |
| F | E | 0° | S 15° E | 10.21 | +3°24′ | 1018′ |
| | G | 263°20′ | N 66° E | 4.98 | −2°16′ | 498′ |
| | | | | | | |
| G | F | 0° | S 67° W | 4.99 | +2°16′ | 499′ |

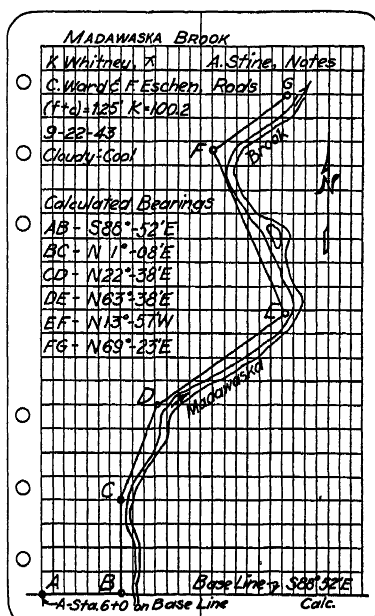



FIG. 1.

STADIA TOPOGRAPHY

All Horiz ∡'s measured clockwise

Sta. Occupied 21+0, El. 221.6, H.I. = 4.5

| Obj. | Horiz.∡ | Rod Int. | Ver. ∡ | Hor. Dist. | Diff. El. |
|---|---|---|---|---|---|
| 1 | 0° | 2.98 | +3°15' | 298' | +16.9 |
| 2 | 340° | 2.72 | +3°11' | 272' | +15.1 |
| 3 | 349° | 2.21 | +3°01' | 221' | +11.6 |
| 4 | 345°27' | 1.31 | +2°11' | 132' | +5.0 |
| 5 | 340°10' | 1.11 | +2°10' | 112' | +4.2 |
| 6 | 329° | 1.62 | +4°12' | 162' | +11.8 |
| 7 | 310°05' | 1.43 | +2°15' | 144' | +5.6 |
| 8 | 310°03' | 1.25 | +2°03' | 126' | +4.5 |
| 9 | 298°45' | 0.79 | +5°10' | 79' | +7.1 |
| 10 | 290°02' | 1.15 | +5°12' | 115' | +10.4 |
| 11 | 310° | 0.45 | +1°30' | 46' | +1.2 |

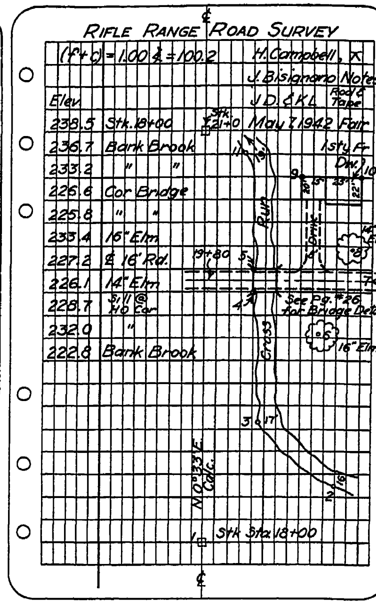



FIG. 2.

CROSS SECTIONS

| Sta. | B.S. (+) | H.I. | F.S. (−) | Elev. |
|---|---|---|---|---|
| B.M.6 | 6.07 | 212.27 | | 206.20 |
| 25 | | | | |
| +50 | | | | |
| 26 | | | | |
| +37 | | | | |
| 27 | | | | |
| +50 | | | | |
| 28 | | | | |
| +50 | | | | |
| 29 | | | | |
| T.P. | | | 3.51 | 208.76 |

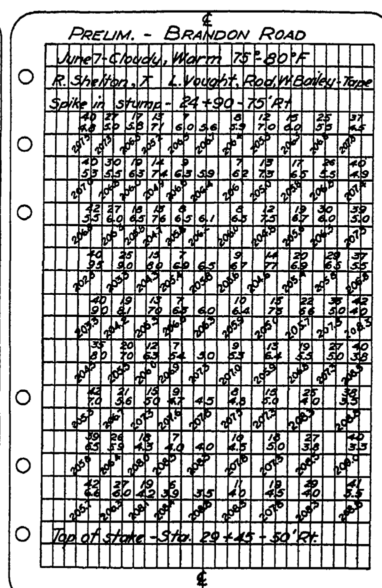



FIG. 3.

## Table 1. Stadia Reductions *

### Differences in Elevation for 100 ft. Inclined Distance

| Minutes | 0° | 1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° | 10° | 11° | 12° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 1.74 | 3.49 | 5.23 | 6.96 | 8.68 | 10.40 | 12.10 | 13.78 | 15.45 | 17.10 | 18.73 | 20.34 |
| 2 | 0.06 | 1.80 | 3.55 | 5.28 | 7.02 | 8.74 | 10.45 | 12.15 | 13.84 | 15.51 | 17.16 | 18.78 | 20.39 |
| 4 | 0.12 | 1.86 | 3.60 | 5.34 | 7.07 | 8.80 | 10.51 | 12.21 | 13.89 | 15.56 | 17.21 | 18.84 | 20.44 |
| 6 | 0.17 | 1.92 | 3.66 | 5.40 | 7.13 | 8.85 | 10.57 | 12.26 | 13.95 | 15.62 | 17.26 | 18.89 | 20.50 |
| 8 | 0.23 | 1.98 | 3.72 | 5.46 | 7.19 | 8.91 | 10.62 | 12.32 | 14.01 | 15.67 | 17.32 | 18.95 | 20.55 |
| **10** | 0.29 | 2.04 | 3.78 | 5.52 | 7.25 | 8.97 | 10.68 | 12.38 | 14.06 | 15.73 | 17.37 | 19.00 | 20.60 |
| 12 | 0.35 | 2.09 | 3.84 | 5.57 | 7.30 | 9.03 | 10.74 | 12.43 | 14.12 | 15.78 | 17.43 | 19.05 | 20.66 |
| 14 | 0.41 | 2.15 | 3.90 | 5.63 | 7.36 | 9.08 | 10.79 | 12.49 | 14.17 | 15.84 | 17.48 | 19.11 | 20.71 |
| 16 | 0.47 | 2.21 | 3.95 | 5.69 | 7.42 | 9.14 | 10.85 | 12.55 | 14.23 | 15.89 | 17.54 | 19.16 | 20.76 |
| 18 | 0.52 | 2.27 | 4.01 | 5.75 | 7.48 | 9.20 | 10.91 | 12.60 | 14.28 | 15.95 | 17.59 | 19.21 | 20.81 |
| **20** | 0.58 | 2.33 | 4.07 | 5.80 | 7.53 | 9.25 | 10.96 | 12.66 | 14.34 | 16.00 | 17.65 | 19.27 | 20.87 |
| 22 | 0.64 | 2.38 | 4.13 | 5.86 | 7.59 | 9.31 | 11.02 | 12.72 | 14.40 | 16.06 | 17.70 | 19.32 | 20.92 |
| 24 | 0.70 | 2.44 | 4.18 | 5.92 | 7.65 | 9.37 | 11.08 | 12.77 | 14.45 | 16.11 | 17.76 | 19.38 | 20.97 |
| 26 | 0.76 | 2.50 | 4.24 | 5.98 | 7.71 | 9.43 | 11.13 | 12.83 | 14.51 | 16.17 | 17.81 | 19.43 | 21.03 |
| 28 | 0.81 | 2.56 | 4.30 | 6.04 | 7.76 | 9.48 | 11.19 | 12.88 | 14.56 | 16.22 | 17.86 | 19.48 | 21.08 |
| **30** | 0.87 | 2.62 | 4.36 | 6.09 | 7.82 | 9.54 | 11.25 | 12.94 | 14.62 | 16.28 | 17.92 | 19.54 | 21.13 |
| 32 | 0.93 | 2.67 | 4.42 | 6.15 | 7.88 | 9.60 | 11.30 | 13.00 | 14.67 | 16.33 | 17.97 | 19.59 | 21.18 |
| 34 | 0.99 | 2.73 | 4.48 | 6.21 | 7.94 | 9.65 | 11.36 | 13.05 | 14.73 | 16.39 | 18.03 | 19.64 | 21.24 |
| 36 | 1.05 | 2 79 | 4.53 | 6.27 | 7.99 | 9.71 | 11.42 | 13.11 | 14.79 | 16.44 | 18.08 | 19.70 | 21.29 |
| 38 | 1.11 | 2.85 | 4.59 | 6.33 | 8.05 | 9.77 | 11.47 | 13.17 | 14.84 | 16.50 | 18.14 | 19.75 | 21.34 |
| **40** | 1.16 | 2.91 | 4.65 | 6.38 | 8.11 | 9.83 | 11.53 | 13.22 | 14.90 | 16.55 | 18.19 | 19.80 | 21.39 |
| 42 | 1.22 | 2.97 | 4.71 | 6.44 | 8.17 | 9.88 | 11.59 | 13.28 | 14.95 | 16.61 | 18.24 | 19.86 | 21.45 |
| 44 | 1.28 | 3.02 | 4.76 | 6.50 | 8.22 | 9.94 | 11.64 | 13.33 | 15.01 | 16.66 | 18.30 | 19.91 | 21.50 |
| 46 | 1.34 | 3.08 | 4.82 | 6.56 | 8.28 | 10.00 | 11.70 | 13.39 | 15.06 | 16.72 | 18.35 | 19.96 | 21.55 |
| 48 | 1.40 | 3.14 | 4.88 | 6.61 | 8.34 | 10.05 | 11.76 | 13.45 | 15.12 | 16.77 | 18.41 | 20.02 | 21.60 |
| **50** | 1.45 | 3.20 | 4.94 | 6.67 | 8.40 | 10.11 | 11.81 | 13.50 | 15.17 | 16.83 | 18.46 | 20.07 | 21.66 |
| 52 | 1.51 | 3.26 | 4.99 | 6.73 | 8.45 | 10.17 | 11.87 | 13.56 | 15.23 | 16.88 | 18.51 | 20.12 | 21.71 |
| 54 | 1.57 | 3.31 | 5.05 | 6.79 | 8.51 | 10.22 | 11.93 | 13.61 | 15.28 | 16.94 | 18.57 | 20.18 | 21.76 |
| 56 | 1.63 | 3.37 | 5.11 | 6.84 | 8.57 | 10.28 | 11.98 | 13.67 | 15.34 | 16.99 | 18.62 | 20.23 | 21.81 |
| 58 | 1.69 | 3.43 | 5.17 | 6.90 | 8.63 | 10.34 | 12.04 | 13.73 | 15.40 | 17.05 | 18.68 | 20.28 | 21.87 |
| **60** | 1.74 | 3.49 | 5.23 | 6.96 | 8.68 | 10.40 | 12.10 | 13.78 | 15.45 | 17.10 | 18.73 | 20.34 | 21.92 |
| $f+c$ | | | | | | | | | | | | | |
| .75 | 0.01 | 0.02 | 0.03 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.11 | 0.12 | 0.14 | 0.15 | 0.16 |
| 1.00 | 0.01 | 0.03 | 0.04 | 0.06 | 0.08 | 0.09 | 0.11 | 0.13 | 0.15 | 0.16 | 0.18 | 0.20 | 0.22 |
| 1.25 | 0.02 | 0.03 | 0.05 | 0.08 | 0.10 | 0.11 | 0.14 | 0.16 | 0.18 | 0.21 | 0.23 | 0.25 | 0.27 |

### Corrections to Horizontal Distances

| Minutes | 0° | 1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° | 10° | 11° | 12° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | ...... | 0.03 | 0.12 | 0.27 | 0.49 | 0.76 | 1.09 | 1.49 | 1.94 | 2.45 | 3.02 | 3.64 | 4.32 |
| **10** | ...... | 0.04 | 0.14 | 0.31 | 0.53 | 0.81 | 1.15 | 1.56 | 2.02 | 2.54 | 3.12 | 3.75 | 4.44 |
| **20** | ...... | 0.05 | 0.17 | 0.34 | 0.57 | 0.86 | 1.22 | 1.63 | 2.10 | 2.63 | 3.22 | 3.86 | 4.56 |
| **30** | 0.01 | 0.07 | 0.19 | 0.37 | 0.62 | 0.92 | 1.28 | 1.70 | 2.18 | 2.72 | 3.32 | 3.97 | 4.68 |
| **40** | 0.01 | 0.08 | 0.22 | 0.41 | 0.66 | 0.98 | 1.35 | 1.78 | 2.27 | 2.82 | 3.42 | 4.09 | 4.81 |
| **50** | 0.02 | 0.10 | 0.24 | 0.45 | 0.71 | 1.03 | 1.42 | 1.86 | 2.36 | 2.92 | 3.53 | 4.21 | 4.93 |

## Table 1. Stadia Reductions (Continued) *

Differences in Elevation for 100 ft. Inclined Distance

| Minutes | 13° | 14° | 15° | 16° | 17° | 18° | 19° | 20° | 21° | 22° | 23° | 24° | 25° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.92 | 23.47 | 25.00 | 26.50 | 27.96 | 29.39 | 30.78 | 32.14 | 33.46 | 34.73 | 35.97 | 37.16 | 38.30 |
| 2 | 21.97 | 23.52 | 25.05 | 26.55 | 28.01 | 29.44 | 30.83 | 32.18 | 33.50 | 34.77 | 36.01 | 37.20 | 38.34 |
| 4 | 22.02 | 23.58 | 25.10 | 26.59 | 28.06 | 29.48 | 30.87 | 32.23 | 33.54 | 34.82 | 36.05 | 37.23 | 38.38 |
| 6 | 22.08 | 23.63 | 25.15 | 26.64 | 28.10 | 29.53 | 30.92 | 32.27 | 33.59 | 34.86 | 36.09 | 37.37 | 38.41 |
| 8 | 22.13 | 23.68 | 25.20 | 26.69 | 28.15 | 29.58 | 30.97 | 32.32 | 33.63 | 34.90 | 36.13 | 37.31 | 38.45 |
| 10 | 22.18 | 23.73 | 25.25 | 26.74 | 28.20 | 29.62 | 31.01 | 32.36 | 33.67 | 34.94 | 36.17 | 37.35 | 38.49 |
| 12 | 22.23 | 23.78 | 25.30 | 26.79 | 28.25 | 29.67 | 31.06 | 32.41 | 33.72 | 34.98 | 36.21 | 37.39 | 38.53 |
| 14 | 22.28 | 23.83 | 25.35 | 26.84 | 28.30 | 29.72 | 31.10 | 32.45 | 33.76 | 35.02 | 36.25 | 37.43 | 38.56 |
| 16 | 22.34 | 23.88 | 25.40 | 26.89 | 28.34 | 29.76 | 31.15 | 32.49 | 33.80 | 35.07 | 36.29 | 37.47 | 38.60 |
| 18 | 22.39 | 23.93 | 25.45 | 26.94 | 28.39 | 29.81 | 31.19 | 32.54 | 33.84 | 35.11 | 36.33 | 37.51 | 38.64 |
| 20 | 22.44 | 23.99 | 25.50 | 26.99 | 28.44 | 29.86 | 31.24 | 32.58 | 33.89 | 35.15 | 36.37 | 37.54 | 38.67 |
| 22 | 22.49 | 24.04 | 25.55 | 27.04 | 28.49 | 29.90 | 31.28 | 32.63 | 33.93 | 35.19 | 36.41 | 37.58 | 38.71 |
| 24 | 22.54 | 24.09 | 25.60 | 27.09 | 28.54 | 29.95 | 31.33 | 32.67 | 33.97 | 35.23 | 36.45 | 37.62 | 38.75 |
| 26 | 22.60 | 24.14 | 25.65 | 27.13 | 28.58 | 30.00 | 31.38 | 32.72 | 34.01 | 35.27 | 36.49 | 37.66 | 38.78 |
| 28 | 22.65 | 24.19 | 25.70 | 27.18 | 28.63 | 30.04 | 31.42 | 32.76 | 34.06 | 35.31 | 36.53 | 37.70 | 38.82 |
| 30 | 22.70 | 24.24 | 25.75 | 27.23 | 28.68 | 30.09 | 31.47 | 32.80 | 34.10 | 35.36 | 36.57 | 37.74 | 38.86 |
| 32 | 22.75 | 24.29 | 25.80 | 27.28 | 28.73 | 30.14 | 31.51 | 32.85 | 34.14 | 35.40 | 36.61 | 37.77 | 38.89 |
| 34 | 22.80 | 24.34 | 25.85 | 27.33 | 28.77 | 30.19 | 31.56 | 32.89 | 34.18 | 35.44 | 36.65 | 37.81 | 38.93 |
| 36 | 22.85 | 24.39 | 25.90 | 27.38 | 28.82 | 30.23 | 31.60 | 32.93 | 34.23 | 35.48 | 36.69 | 37.85 | 38.97 |
| 38 | 22.91 | 24.44 | 25.95 | 27.43 | 28.87 | 30.28 | 31.65 | 32.98 | 34.27 | 35.52 | 36.73 | 37.89 | 39.00 |
| 40 | 22.96 | 24.49 | 26.00 | 27.48 | 28.92 | 30.32 | 31.69 | 33.02 | 34.31 | 35.56 | 36.77 | 37.93 | 39.04 |
| 42 | 23.01 | 24.55 | 26.05 | 27.52 | 28.96 | 30.37 | 31.74 | 33.07 | 34.35 | 35.60 | 36.80 | 37.96 | 39.08 |
| 44 | 23.06 | 24.60 | 26.10 | 27.57 | 29.01 | 30.41 | 31.78 | 33.11 | 34.40 | 35.64 | 36.84 | 38.00 | 39.11 |
| 46 | 23.11 | 24.65 | 26.15 | 27.62 | 29.06 | 30.46 | 31.83 | 33.15 | 34.44 | 35.68 | 36.88 | 38.04 | 39.15 |
| 48 | 23.16 | 24.70 | 26.20 | 27.67 | 29.11 | 30.51 | 31.87 | 33.20 | 34.48 | 35.72 | 36.92 | 38.08 | 39.18 |
| 50 | 23.22 | 24.75 | 26.25 | 27.72 | 29.15 | 30.55 | 31.92 | 33.24 | 34.52 | 35.76 | 36.96 | 38.11 | 39.22 |
| 52 | 23.27 | 24.80 | 26.30 | 27.77 | 29.20 | 30.60 | 31.96 | 33.28 | 34.57 | 35.80 | 37.00 | 38.15 | 39.26 |
| 54 | 23.32 | 24.85 | 26.35 | 27.81 | 29.25 | 30.65 | 32.01 | 33.33 | 34.61 | 35.85 | 37.04 | 38.19 | 39.29 |
| 56 | 23.37 | 24.90 | 26.40 | 27.86 | 29.30 | 30.69 | 32.05 | 33.37 | 34.65 | 35.89 | 37.08 | 38.23 | 39.33 |
| 58 | 23.42 | 24.95 | 26.45 | 27.91 | 29.34 | 30.74 | 32.09 | 33.41 | 34.69 | 35.93 | 37.12 | 38.26 | 39.36 |
| 60 | 23.47 | 25.00 | 26.50 | 27.96 | 29.39 | 30.78 | 32.14 | 33.46 | 34.73 | 35.97 | 37.16 | 38.30 | 39.40 |
| $f+c$ | | | | | | | | | | | | | |
| .75 | 0.17 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.29 | 0.30 | 0.31 | 0.32 |
| 1.00 | 0.23 | 0.25 | 0.27 | 0.28 | 0.30 | 0.32 | 0.33 | 0.35 | 0.37 | 0.38 | 0.40 | 0.41 | 0.43 |
| 1.25 | 0.29 | 0.31 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 |

Corrections to Horizontal Distances

| Minutes | 13° | 14° | 15° | 16° | 17° | 18° | 19° | 20° | 21° | 22° | 23° | 24° | 25° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5.06 | 5.85 | 6.70 | 7.60 | 8.55 | 9.55 | 10.60 | 11.70 | 12.84 | 14.03 | 15.27 | 16.54 | 17.86 |
| 10 | 5.19 | 5.99 | 6.84 | 7.75 | 8.71 | 9.72 | 10.78 | 11.89 | 13.04 | 14.24 | 15.48 | 16.76 | 18.08 |
| 20 | 5.32 | 6.13 | 6.99 | 7.91 | 8.88 | 9.89 | 10.96 | 12.07 | 13.23 | 14.44 | 15.69 | 16.98 | 18.31 |
| 30 | 5.45 | 6.27 | 7.14 | 8.07 | 9.04 | 10.07 | 11.14 | 12.26 | 13.43 | 14.64 | 15.90 | 17.20 | 18.53 |
| 40 | 5.58 | 6.41 | 7.29 | 8.23 | 9.21 | 10.24 | 11.33 | 12.46 | 13.63 | 14.85 | 16.11 | 17.42 | 18.76 |
| 50 | 5.72 | 6.55 | 7.44 | 8.39 | 9.38 | 10.42 | 11.51 | 12.65 | 13.83 | 15.06 | 16.33 | 17.64 | 18.99 |

* *From Eshbach, Handbook of Engineering Fundamentals, John Wiley & Sons, 1936.*

## STAKEOUT FOR STRUCTURES

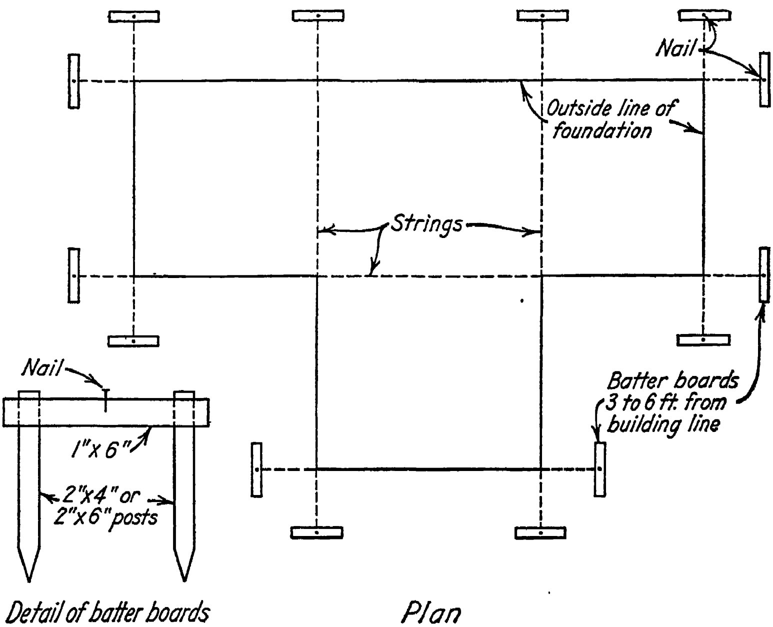



FIG. 4. Batter boards for structures.

Batter boards as illustrated are set on, or parallel to, the building or structure lines either before or after the rough excavation is completed. When set before excavating, the batter boards should be checked upon completion of the rough excavation. Points on the batter boards may be set on the outside foundation line or sometimes on the center line of columns. It is preferable to set the top of each batter board to some definite grade, such as the first-floor elevation or else some even foot above or below a working grade.

Before setting the batter boards a base line should be established and referenced in with ties. Targets may also be set on the base line projected. Angles turned from the base line should be established by the method of repetition (see p. 244) as an error of 1 minute in 300 ft. will throw the building line off 1 in.

From time to time during construction, the batter boards should be checked for disturbance or movement.

## HIGHWAY CONSTRUCTION STAKEOUT

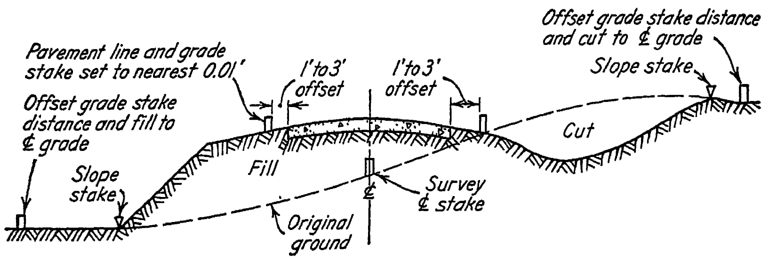



FIG. 5. Highway construction stakeout.

Before work begins, the construction centerline is staked out, usually on 50-ft. stations. Hubs are set at P.C.'s, P.T.'s, P.I.'s, and transit points. These hubs are tied in or offset, and the ties are recorded in the field book.

Offset grade stakes are set on 50-ft. stations far enough out to escape disturbance during operations where possible. Elevations of these stake tops are taken with a level, and the cut or fill to finish center-line grade is computed and marked on each stake. The distance to the toe or top of slope is marked on the offset grade stake or else the actual location of the toe or top of slope is marked with a slope stake. The station and the distance from the offset stake to center line are marked on the face of the offset stake. The superelevation plus or minus to edge of pavement and any pavement widening or curves are also marked on the offset stakes.

After rough grading is completed, blue tops or fine grade stakes are set every 50 ft. minimum. Blue tops are stakes set to fine grade and the top marked blue. Allowance for settlement or subsidence is sometimes made in setting these grades, or it may be made the contractor's responsibility, the engineer in the latter case setting the stakes to the grades shown on plan.

For concrete pavement, stakes are set usually every 50 ft. on tangents and straight grades and every 25 ft. on horizontal and vertical curves. These stakes are carefully aligned with a transit and tacks set on line. Either the tops are set to exact grade or the cut or fill is marked to finish grade.

Pavement stakes are set with a sufficient offset to allow room for the flanged bases of the forms, the offset usually being about 18 in. or 2 ft. from the edge of pavement. After the initial lane is placed, additional stakes may be set for other lanes or the forms may be set by leveling over with a line level.

For asphaltic pavements stakes are usually not set when the base has been constructed true to grade as the paving machines can be set for the required thickness. If the base is variable, steel pins for line and grade are usually set at 50- or 25-ft. intervals and offset enough to allow the machines to work. A 1-ft. offset is usually sufficient.

The amount of stakeout done for highway construction depends on the value and importance of the work, and judgment is required. For example, on cheap tertiary road construction only center-line stakes might be set at 100-ft. stations and a list of cuts and fill given to the foreman. The line and grade may then be transferred by the foreman, using a tape and hand level, to convenient trees, offset stakes, etc.

Through wooded country, stakes or marks are usually set at the clearing and grubbing limits. Trees to be saved are indicated by markings or signs.

In addition to line and grade stakes, right-of-way stakes may be necessary, also project markers and stakes set at intersection of right-of-way and adjoining property lines.

## RAILROAD CONSTRUCTION STAKEOUT

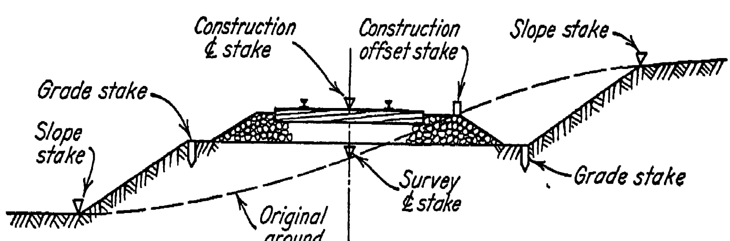



Fig. 6. Railroad construction stakeout.

Stakeout for the grading work is similar to highway stakeout.

After grading is finished, and the ballast, ties, and rails are being installed, stakes for exact alignment and grade of rails are set. These stakes are tacked for line and may be set on center line or offset about 2 ft. from one rail. The grade marked is usually finish grade to the near rail, superelevation being set for the other rail by using a track level.

## AIRFIELD CONSTRUCTION STAKEOUT

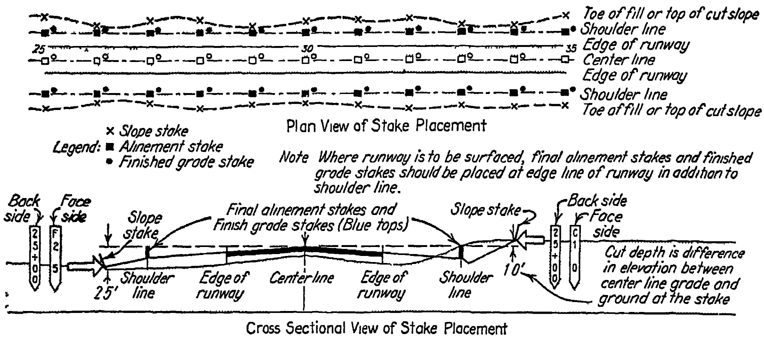



FIG. 7. Airport stakeout.

The stakeout required differs from highway work in that the widths of runways and taxiways, together with their shoulders and graded areas, are so great that it is not practicable to set offset stakes to serve during construction.

The construction center line is staked out at 50-ft. stations and well referenced and tied in, and targets are set on the line extended. During grading operations stakes are set continually day by day, at least one party usually being required at all times for each runway under construction.

For rough grading stakes at 50-ft. intervals both longitudinally and transversely are sufficient, but for fine grading stakes should be set at 25-ft. intervals.

Concrete pavement stakes are set exactly the same as for highways, but owing to the widths of runways and aprons it is not desirable to depend on a string level to transfer the grades for more than 2 or 3 lanes. Additional stake lines should be run in at intervals of 25 or 30 ft. transversely.

Stakeout for asphaltic pavements is the same as for highways.

Stakes for grading interior areas are usually set on 50- to 100-ft. grids and marked for cut and fill.

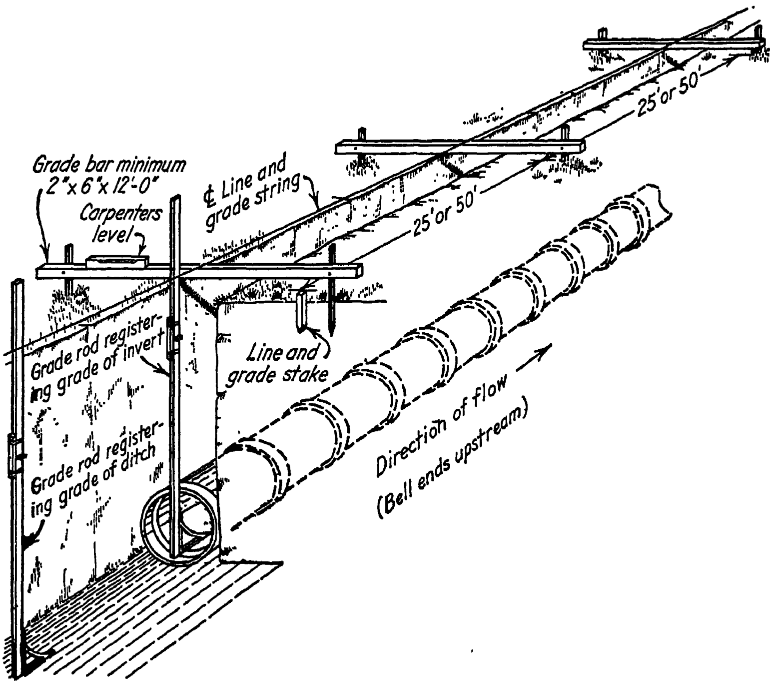



FIG. 8. Pipeline stakeout.

Before beginning excavation, stakes should be set 25 or 50 ft. apart parallel to and offset from the center line of the drain on the side opposite to that on which earth will be thrown. Elevations of tops of stakes should be taken with a level and depth of cut marked on each. These stakes will serve as guides for the rough excavation.

Excavation should be begun at the outlet.

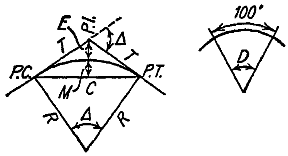
After the excavation is approximately to grade, batter boards should be placed across the trench opposite each stake with the top of each board at the same distance above the grade of the flow line. About 6.5 or 7 ft. above grade is good practice. The center line is then marked on the batter boards, and a string connecting these points will be directly above and parallel to the grade line. The center line at any point may then be obtained by dropping a plumb bob from the string, and the grade determined by measuring down from the string with a pole of proper length.

Laying of pipe should begin at the outlet and proceed upstream.

* *From Principles of Highway Construction Applied to Airports, Flight Strips and other Landing Areas for Aircraft, Public Roads Administration.*

# CIRCULAR CURVES

## ARC DEFINITION




FORMULAS

$$R = \frac{5729.58}{D}$$

$$T = R \tan \frac{\Delta}{2}; \quad T = \frac{\tan 1^\circ \text{ curve for } \Delta}{D}$$

$$L = \text{length} = \frac{100\Delta}{D}$$

$$M = R(1 - \cos \tfrac{1}{2}\Delta)$$

$$E = R\left(\frac{1}{\cos \frac{1}{2}\Delta} - 1\right); \quad E = \frac{\text{ext. } 1^\circ \text{ curve for } \Delta}{D}$$

$$C = 2R \sin \frac{\Delta}{2}$$

DEFINITIONS

$L$ = Length of circular curve.
P.I. = point of intersection.
P.C. = point of curvature.
P.T. = point of tangency.

EXAMPLE. *Given.* $\Delta = 54^\circ 20'$; $D = 7^\circ 40'$; P.I. = Sta. 125 + 39.88.
*Required.* $R$; $T$; $L$ and Sta. of P.C. and P.T.
*Solution.*

$$R = \frac{5729.58}{7^\circ 40'} = 747.34'.$$

$T = 747.34 (\tan 27^\circ 10') = 747.34(0.513195) = 383.53'$.

Also, from p. 208 (funct. 1° curve) by interpolation, tan 1° curve for $\Delta 54^\circ 20' = 2940.41$.

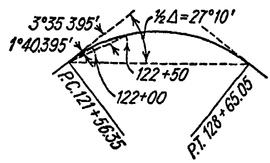
$$\therefore T = \frac{2940.41}{7^\circ 40'} = 383.53'.$$

P.C. = Sta. 125 + 39.88 − 383.53 = Sta. 121 + 56.35.

$$L = \frac{100\Delta}{D} = \frac{100(54^\circ 20')}{7^\circ 40'} = 708.70'.$$

P.T. = Sta. 121 + 56.35 + 708.70 = Sta. 128 + 65.05.

## DEFLECTIONS




FORMULAS

Deflection angle $= \frac{D}{2}$ for 100′; $\frac{D}{4}$ for 50′, etc.

For $c$ feet (in minutes) $= 0.3\ cD$.

Deflection angle (in minutes) from P.C. to P.T. $= 0.3LD$.

Also, deflection angle (in degrees) from P.C. to P.T. $= \frac{\Delta}{2}$.

EXAMPLE. *Given.* $\Delta = 54°\ 20'$; $D = 7°\ 40'$; $L = 708.70$; P.C. = Sta. 121 + 56.35; P.T. = Sta. 128 + 65.05.

*Required.* Deflection angle from P.C. to Sta. 122 + 00; Sta. 122 + 50 and P.T. Sta. 128 + 65.05.

*Solution.*

Sta. 122 + 00 − P.C. Sta. 121 + 56.35 = 43.65′.

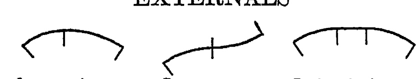
$\therefore$ Deflection angle to Sta. 122 + 00 $= 0.3 \times 43.65 \times 7°\ 40' = 100.395' = 1°\ 40.395'$.

Deflection angle to Sta. 122 + 50 $= 1°\ 40.395' + \frac{7°\ 40'}{4} = 1°\ 40.395' + 1°\ 55' = 3°\ 35.395'$.

Deflection angle to P.T. Sta. 128 + 65.05 $= 0.3 \times 708.70 \times 7°\ 40' = 27°\ 10'$.

Also, deflection angle to P.T. Sta. 128 + 65.05 $= \frac{\Delta}{2} = \frac{54°\ 20'}{2} = 27°\ 10'$.

## EXTERNALS



Compound curve Avoid | Reverse curve Avoid | Broken-back curve Avoid

EXAMPLE. *Given.* $\Delta = 54°\ 20'$; $D = 7°\ 40'$; $R = 747.34'$.

*Required.* External "$E$".

*Solution.*

$$E = 747.34\left(\frac{1}{.8896822} - 1\right) = 92.67'.$$

Also, from p. 208 (funct. 1° curve) by interpolation, external 1° curve for $\Delta 54°\ 20' = 710.48$.

$$\therefore E = \frac{710.48}{7°\ 40'} = 92.67'.$$

## MINIMUM CURVATURE *

The curve should be at least 500 ft. long for $\Delta = 5$ degrees and increase 100 ft. in length for each decrease of 1 degree in the $\Delta$.

Where topography permits, use simple 0° 20′ to 1° 00′ curves without superelevation or widening.

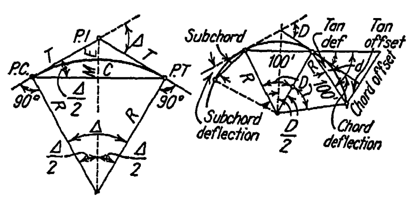
## MAXIMUM CURVATURE *

| | Degree of Curve | |
|---|---|---|
| Assumed Design Speed, M.P.H. | Desirable Maximum | Absolute Maximum |
| 30 | 20 | 25 |
| 40 | 11 | 14 |
| 50 | 7 | 9 |
| 60 | 5 | 6 |
| 70 | 3 | 4 |

## TANGENT OFFSETS

The approximate offset from the tangent to the curve at any distance from the P.C. $= \dfrac{\text{distance}^2}{2R}$.

## CHORD DEFINITION (R. R. CURVE)




$D$ (in degrees) subtends 100′ chord.

$$D = 100\,\Delta/L$$

$$D = \frac{\tan 1^\circ \text{ curve}}{T} \text{ (approx.).}$$

$$D = \frac{\text{ext. } 1^\circ \text{ curve}}{E} \text{ (approx.).}$$

Tan offset $= \dfrac{\text{chord}^2}{2R} = \text{chord} \cdot \sin \text{def.} = \left(\dfrac{\text{chord}^2}{100}\right)$ tan offset, Table 3.

Chord offset $= 2$ tan deflection for 100′ chord $= 100 \sin D^\circ$.

* *From Geometric Design Standards by A.A.S.H.O.*

Tan def. $= \frac{1}{2}D \dfrac{\text{chord}}{100}$; for $c$ feet $= 0.3D \times c =$ def. for 1′ in Table 2 $\times c$.

Chord def. = 2 tan def. = $D$ for 100′ chord.

FORMULAS

$$R = \frac{50}{\sin D/2}; \quad R = T \cdot \text{cotan}\,\frac{\Delta}{2}; \quad R = \frac{E}{\text{exsec}\,\Delta/2}; \quad T = R \cdot \tan\frac{\Delta}{2};$$

$$T = \frac{50 \tan \Delta/2}{\sin \Delta/2}; \quad T = \frac{\tan 1^\circ \text{ curve}}{D} + \text{corr.}^* \quad L = 100\,\frac{\Delta}{D}; \quad \Delta = \frac{DL}{100};$$

$$M = R\left(1 - \cos\frac{\Delta}{2}\right); \quad M = R \text{ vers}\,\frac{\Delta}{2}; \quad E = T \cdot \tan\frac{\Delta}{4};$$

$$E = \frac{R}{\cos \Delta/2} - R; \quad E = R \cdot \text{exsec}\,\frac{\Delta}{2}. \quad C = 2R \cdot \sin\frac{\Delta}{2};$$

$$E = \frac{\text{ext. } 1^\circ \text{ curve}}{D} + \text{correction.}^* \quad \sin\frac{D}{2} = \frac{50}{R}; \quad \sin\frac{D}{2} = \frac{50 \tan \Delta/2}{T}$$

EXAMPLE. *Given.* $\Delta = 54^\circ 20'$; $D = 7^\circ 40'$, P.I. Sta. 125 + 39.88.
*Required.* $R$, $T$, $L$, P.C., and P.T.
*Solution.*
$R = 50 \div \sin 3^\circ 50' = 747.89$.
$T = 747.89\ (\tan 27^\circ 10') = 383.81$.
$L = 100\Delta \div D = 100\ (54^\circ 20') \div 7^\circ 40' = 708.70$.
P.C. = P.I. Sta. 125 + 39.88 − 383.81 = Sta. 121 + 56.07.
P.T. = Sta. 121 + 56.07 + 708.70 = Sta. 128 + 64.77.

* See p. 209.

TABLE 2. RADII, DEFLECTIONS, OFFSETS, ORDINATES, CHORDS AND ARCS—100′ CHORDS *

| *D* | Radius | Def. for 1 Ft. | Tan Off-set | Mid Ord. | For Subchords Add | | | | Actual Arc per 100′ Sta. | Long Chords | | | | *D* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10′ | 20′ | 25′ | 50′ | | 2 Sta. | 3 Sta. | 4 Sta. | 5 Sta. | |
| 30′ | 11,459.2 | 0.15 | 0.436 | 0.109 | | | | | 100.000 | 200.000 | 299.99 | 399.98 | 499.96 | 30′ |
| 1° | 5,729.65 | 0.30 | 0.873 | 0.218 | | | | | 100.001 | 199.99 | 299.97 | 399.92 | 499.85 | 1° |
| 30′ | 3,819.83 | 0.45 | 1.309 | 0.327 | | | | | 100.003 | 199.98 | 299.93 | 399.83 | 499.66 | 30′ |
| 2° | 2,864.93 | 0.60 | 1.745 | 0.436 | | | | | 100.005 | 199.97 | 299.88 | 399.70 | 499.39 | 2° |
| 30′ | 2,292.01 | 0.75 | 2.181 | 0.545 | | | | | 100.008 | 199.95 | 299.81 | 399.52 | 499.05 | 30′ |
| 3° | 1,910.08 | 0.90 | 2.618 | 0.654 | | | | | 100.011 | 199.93 | 299.73 | 399.32 | 498.63 | 3° |
| 30′ | 1,637.28 | 1.05 | 3.054 | 0.764 | | | | | 100.015 | 199.91 | 299.63 | 399.07 | 498.14 | 30′ |
| 4° | 1,432.69 | 1.20 | 3.490 | 0.872 | | | | 0.01 | 100.020 | 199.88 | 299.51 | 398.78 | 497.57 | 4° |
| 30′ | 1,273.57 | 1.35 | 3.926 | 0.982 | | | | 0.01 | 100.026 | 199.85 | 299.38 | 398.46 | 496.92 | 30′ |
| 5° | 1,146.28 | 1.50 | 4.362 | 1.091 | | | 0.01 | 0.01 | 100.032 | 199.81 | 299.24 | 398.10 | 496.20 | 5° |
| 30′ | 1,042.14 | 1.65 | 4.798 | 1.200 | | | 0.01 | 0.01 | 100.038 | 199.77 | 299.08 | 397.70 | 495.41 | 30′ |
| 6° | 955.37 | 1.80 | 5.234 | 1.309 | | 0.01 | 0.01 | 0.02 | 100.046 | 199.73 | 298.90 | 397.26 | 494.53 | 6° |
| 30′ | 881.95 | 1.95 | 5.669 | 1.418 | | 0.01 | 0.01 | 0.02 | 100.054 | 199.68 | 298.71 | 396.79 | 493.59 | 30′ |
| 7° | 819.02 | 2.10 | 6.105 | 1.528 | | 0.01 | 0.01 | 0.02 | 100.062 | 199.63 | 298.51 | 396.28 | 492.57 | 7° |
| 8° | 716.78 | 2.40 | 6.976 | 1.746 | 0.01 | 0.02 | 0.02 | 0.03 | 100.081 | 199.51 | 298.05 | 395.14 | 490.31 | 8° |
| 10° | 573.69 | 3.00 | 8.716 | 2.183 | 0.01 | 0.02 | 0.03 | 0.05 | 100.127 | 199.24 | 296.96 | 392.42 | 484.90 | 10° |
| 12° | 478.34 | 3.60 | 10.45 | 2.620 | 0.02 | 0.04 | 0.04 | 0.07 | 100.183 | 198.90 | 295.63 | 389.12 | 478.34 | 12° |
| 14° | 410.28 | 4.20 | 12.18 | 3.058 | 0.02 | 0.05 | 0.06 | 0.09 | 100.249 | 198.51 | 294.06 | 385.23 | 470.65 | 14° |
| 16° | 359.27 | 4.80 | 13.92 | 3.496 | 0.03 | 0.06 | 0.08 | 0.12 | 100.326 | 198.05 | 292.25 | 380.76 | 461.86 | 16° |
| 18° | 319.62 | 5.40 | 15.64 | 3.935 | 0.04 | 0.08 | 0.10 | 0.15 | 100.412 | 197.54 | 290.21 | 375.74 | 452.02 | 18° |
| 20° | 287.94 | 6.00 | 17.37 | 4.374 | 0.05 | 0.10 | 0.12 | 0.19 | 100.510 | 196.96 | 287.94 | 370.17 | 441.15 | 20° |
| 22° | 262.04 | 6.60 | 19.08 | 4.814 | 0.06 | 0.12 | 0.14 | 0.23 | 100.617 | 196.33 | 285.44 | 364.06 | 429.31 | 22° |
| 24° | 240.49 | 7.20 | 20.79 | 5.255 | 0.07 | 0.14 | 0.17 | 0.28 | 100.735 | 195.63 | 282.71 | 357.43 | 416.54 | 24° |
| 30° | 193.18 | 9.00 | 25.88 | 6.583 | 0.11 | 0.22 | 0.29 | 0.43 | 101.152 | 193.19 | 273.21 | 334.61 | 373.21 | 30° |

* *Adapted from Railroad Curve Tables by Eugene Dietzgen Co.*

## TABLE 3. MINUTES IN DECIMALS OF A DEGREE, SECONDS IN DECIMALS OF A MINUTE *

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0167 | 11 | 0.1833 | 21 | 0.3500 | 31 | 0.5167 | 41 | 0.6833 | 51 | 0.8500 |
| 2 | 0.0333 | 12 | 0.2000 | 22 | 0.3667 | 32 | 0.5333 | 42 | 0.7000 | 52 | 0.8667 |
| 3 | 0.0500 | 13 | 0.2167 | 23 | 0.3833 | 33 | 0.5500 | 43 | 0.7167 | 53 | 0.8833 |
| 4 | 0.0667 | 14 | 0.2333 | 24 | 0.4000 | 34 | 0.5667 | 44 | 0.7333 | 54 | 0.9000 |
| 5 | 0.0833 | 15 | 0.2500 | 25 | 0.4167 | 35 | 0.5833 | 45 | 0.7500 | 55 | 0.9167 |
| 6 | 0.1000 | 16 | 0.2667 | 26 | 0.4333 | 36 | 0.6000 | 46 | 0.7667 | 56 | 0.9333 |
| 7 | 0.1167 | 17 | 0.2833 | 27 | 0.4500 | 37 | 0.6167 | 47 | 0.7833 | 57 | 0.9500 |
| 8 | 0.1333 | 18 | 0.3000 | 28 | 0.4667 | 38 | 0.6333 | 48 | 0.8000 | 58 | 0.9667 |
| 9 | 0.1500 | 19 | 0.3167 | 29 | 0.4833 | 39 | 0.6500 | 49 | 0.8167 | 59 | 0.9833 |
| 10 | 0.1667 | 20 | 0.3333 | 30 | 0.5000 | 40 | 0.6667 | 50 | 0.8333 | 60 | 1.0000 |

Proportional Part for $1'' = 0.000278$ of $1°$

USE OF TABLES 2 AND 3

| Given | Required | Solution | |
|---|---|---|---|
| $D = 2° 30'$ | Deflection for 35 ft. | $= 0.75 \times 35 = 26.25$ | $= 26' 15''$ |
| $D = 4°$ | Tan offset for 125 ft. | $= 3.49(1.25/100)^2$ | $= 5.45$ ft. |
| $D = 10°$ | Mid ord. for 30 ft. chord | $= 0.0001 \times 30^2 \times 2.183$ | $= 0.196$ ft. |
| $D = 14°$ | Length of nominal 20 ft. sub chord | $= 20 + 0.05$ | $= 20.05$ ft. |
| $D = 20°$ | Actual length of arc for $L = 600$ ft. (6 Sta.) | $= 100.51 \times 6$ | $= 603.06$ ft. |
| $D = 3°$ | Long chord for 3 Sta. | = From Table 2 | $= 299.73$ ft. |
| $\Delta = 27° 05' 11''$ | $\Delta$ in decimals of ° | From Table 3<br>$= 27 + 0.0833 + 11 \times 0.000278 = 27.086°$ | |

* *Adapted from Railroad Curve Tables by Eugene Dietzgen Co.*

## TABLE 4. FUNCTIONS OF 1° CURVE

See pp. 202, 203, 204 for use of table.

| Central Angle | Tangent | External | Central Angle | Tangent | External | Central Angle | Tangent | External | Central Angle | Tangent | External |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1° | 50.00 | 0.22 | 31° | 1588.95 | 216.25 | 61° | 3374.98 | 920.1 | 91° | 5830.46 | 2444.9 |
| 30′ | 75.00 | 0.49 | 30′ | 1615.91 | 223.51 | 30′ | 3408.74 | 937.3 | 30′ | 5881.58 | 2481.5 |
| 2° | 100.01 | 0.87 | 32° | 1642.93 | 230.90 | 62° | 3442.68 | 954.8 | 92° | 5933.15 | 2518.5 |
| 30′ | 125.02 | 1.36 | 30′ | 1670.02 | 238.43 | 30′ | 3476.79 | 972.4 | 30′ | 5985.20 | 2556.0 |
| 3° | 150.03 | 1.96 | 33° | 1697.18 | 246.08 | 63° | 3511.09 | 990.2 | 93° | 6037.72 | 2594.0 |
| 30′ | 175.05 | 2.67 | 30′ | 1724.41 | 253.87 | 30′ | 3545.57 | 1008.3 | 30′ | 6090.72 | 2632.6 |
| 4° | 200.08 | 3.49 | 34° | 1751.71 | 261.80 | 64° | 3580.24 | 1026.6 | 94° | 6144.22 | 2671.6 |
| 30′ | 225.12 | 4.42 | 30′ | 1779.08 | 269.86 | 30′ | 3615.09 | 1045.2 | 30′ | 6198.22 | 2711.2 |
| 5° | 250.16 | 5.46 | 35° | 1806.53 | 278.05 | 65° | 3650.14 | 1063.9 | 95° | 6252.74 | 2751.3 |
| 30′ | 275.21 | 6.61 | 30′ | 1834.05 | 286.39 | 30′ | 3685.39 | 1082.9 | 30′ | 6307.77 | 2792.0 |
| 6° | 300.27 | 7.86 | 36° | 1861.65 | 294.86 | 66° | 3720.83 | 1102.2 | 96° | 6363.34 | 2833.2 |
| 30′ | 325.35 | 9.23 | 30′ | 1889.33 | 303.47 | 30′ | 3756.48 | 1121.7 | 30′ | 6419.45 | 2875.0 |
| 7° | 350.44 | 10.71 | 37° | 1917.09 | 312.22 | 67° | 3792.33 | 1141.4 | 97° | 6476.11 | 2917.3 |
| 30′ | 375.54 | 12.29 | 30′ | 1944.93 | 321.11 | 30′ | 3828.38 | 1161.3 | 30′ | 6533.33 | 2960.3 |
| 8° | 400.65 | 13.99 | 38° | 1972.85 | 330.15 | 68° | 3864.65 | 1181.6 | 98° | 6591.13 | 3003.8 |
| 30′ | 425.78 | 15.80 | 30′ | 2000.86 | 339.32 | 30′ | 3901.13 | 1202.0 | 30′ | 6649.50 | 3047.9 |
| 9° | 450.93 | 17.72 | 39° | 2028.95 | 348.64 | 69° | 3937.83 | 1222.7 | 99° | 6708.47 | 3092.7 |
| 30′ | 476.09 | 19.75 | 30′ | 2057.13 | 358.11 | 30′ | 3974.75 | 1243.7 | 30′ | 6768.05 | 3138.1 |
| 10° | 501.27 | 21.89 | 40° | 2085.40 | 367.72 | 70° | 4011.89 | 1265.0 | 100° | 6828.25 | 3184.1 |
| 30′ | 526.47 | 24.14 | 30′ | 2113.75 | 377.47 | 30′ | 4049.27 | 1286.5 | 30′ | 6889.07 | 3230.8 |
| 11° | 551.70 | 26.50 | 41° | 2142.20 | 387.38 | 71° | 4086.87 | 1308.2 | 101° | 6950.53 | 3278.1 |
| 30′ | 576.94 | 28.97 | 30′ | 2170.74 | 397.43 | 30′ | 4124.71 | 1330.3 | 30′ | 7012.65 | 3326.1 |
| 12° | 602.20 | 31.56 | 42° | 2199.38 | 407.64 | 72° | 4162.78 | 1352.6 | 102° | 7075.44 | 3374.9 |
| 30′ | 627.49 | 34.26 | 30′ | 2228.11 | 417.99 | 30′ | 4201.10 | 1375.2 | 30′ | 7138.91 | 3424.3 |
| 13° | 652.80 | 37.07 | 43° | 2256.94 | 428.50 | 73° | 4239.66 | 1398.0 | 103° | 7203.07 | 3474.4 |
| 30′ | 678.14 | 39.99 | 30′ | 2285.87 | 439.16 | 30′ | 4278.48 | 1421.2 | 30′ | 7267.94 | 3525.2 |
| 14° | 703.50 | 43.03 | 44° | 2314.90 | 449.98 | 74° | 4317.55 | 1444.6 | 104° | 7333.53 | 3576.8 |
| 30′ | 728.89 | 46.18 | 30′ | 2344.03 | 460.95 | 30′ | 4356.87 | 1468.4 | 30′ | 7399.85 | 3629.2 |
| 15° | 754.31 | 49.44 | 45° | 2373.27 | 472.08 | 75° | 4396.46 | 1492.4 | 105° | 7466.93 | 3682.3 |
| 30′ | 779.76 | 52.82 | 30′ | 2402.61 | 483.37 | 30′ | 4436.31 | 1516.7 | 30′ | 7534.78 | 3736.2 |
| 16° | 805.24 | 56.31 | 46° | 2432.06 | 494.82 | 76° | 4476.44 | 1541.4 | 106° | 7603.41 | 3791.0 |
| 30′ | 830.75 | 59.91 | 30′ | 2461.62 | 506.42 | 30′ | 4516.83 | 1566.3 | 30′ | 7672.84 | 3846.5 |
| 17° | 856.29 | 63.63 | 47° | 2491.29 | 518.20 | 77° | 4557.51 | 1591.6 | 107° | 7743.08 | 3902.9 |
| 30′ | 881.87 | 67.47 | 30′ | 2521.07 | 530.13 | 30′ | 4598.47 | 1617.1 | 30′ | 7814.16 | 3960.1 |
| 18° | 907.48 | 71.42 | 48° | 2550.97 | 542.23 | 78° | 4639.72 | 1643.0 | 108° | 7886.09 | 4018.2 |
| 30′ | 933.12 | 75.49 | 30′ | 2580.99 | 554.50 | 30′ | 4681.26 | 1669.2 | 30′ | 7958.89 | 4077.2 |
| 19° | 958.80 | 79.67 | 49° | 2611.12 | 566.94 | 79° | 4723.10 | 1695.8 | 109° | 8032.57 | 4137.1 |
| 30′ | 984.52 | 83.97 | 30′ | 2641.37 | 579.54 | 30′ | 4765.24 | 1722.7 | 30′ | 8107.17 | 4197.9 |
| 20° | 1010.28 | 88.39 | 50° | 2671.75 | 592.32 | 80° | 4807.69 | 1749.9 | 110° | 8182.69 | 4259.7 |
| 30′ | 1036.08 | 92.92 | 30′ | 2702.24 | 605.27 | 30′ | 4850.45 | 1777.4 | 30′ | 8259.15 | 4322.4 |
| 21° | 1061.91 | 97.58 | 51° | 2732.87 | 618.39 | 81° | 4893.52 | 1805.3 | 111° | 8336.59 | 4386.1 |
| 30′ | 1087.79 | 102.35 | 30′ | 2763.62 | 631.69 | 30′ | 4936.92 | 1833.6 | 30′ | 8415.01 | 4450.9 |
| 22° | 1113.72 | 107.24 | 52° | 2794.50 | 645.17 | 82° | 4980.65 | 1862.2 | 112° | 8494.45 | 4516.6 |
| 30′ | 1139.68 | 112.25 | 30′ | 2825.52 | 658.83 | 30′ | 5024.71 | 1891.2 | 30′ | 8574.92 | 4583.4 |
| 23° | 1165.70 | 117.38 | 53° | 2856.66 | 672.66 | 83° | 5069.10 | 1920.5 | 113° | 8656.45 | 4651.3 |
| 30′ | 1191.75 | 122.63 | 30′ | 2887.95 | 686.68 | 30′ | 5113.84 | 1950.3 | 30′ | 8739.06 | 4720.3 |
| 24° | 1217.86 | 128.00 | 54° | 2919.37 | 700.89 | 84° | 5158.93 | 1980.4 | 114° | 8822.78 | 4790.4 |
| 30′ | 1244.01 | 133.50 | 30′ | 2950.93 | 715.28 | 30′ | 5204.38 | 2010.8 | 30′ | 8907.63 | 4861.7 |
| 25° | 1270.22 | 139.11 | 55° | 2982.63 | 729.85 | 85° | 5250.19 | 2041.7 | 115° | 8993.64 | 4934.1 |
| 30′ | 1296.47 | 144.85 | 30′ | 3014.48 | 744.62 | 30′ | 5296.37 | 2073.0 | 30′ | 9080.83 | 5007.8 |
| 26° | 1322.78 | 150.71 | 56° | 3046.47 | 759.58 | 86° | 5342.92 | 2104.7 | 116° | 9169.24 | 5082.7 |
| 30′ | 1349.14 | 156.70 | 30′ | 3078.61 | 774.73 | 30′ | 5389.85 | 2136.7 | 30′ | 9258.89 | 5158.8 |
| 27° | 1375.55 | 162.81 | 57° | 3110.91 | 790.08 | 87° | 5437.17 | 2169.2 | 117° | 9349.82 | 5236.2 |
| 30′ | 1402.02 | 169.04 | 30′ | 3143.35 | 805.62 | 30′ | 5484.88 | 2202.2 | 30′ | 9442.05 | 5315.0 |
| 28° | 1428.54 | 175.41 | 58° | 3175.96 | 821.37 | 88° | 5532.99 | 2235.5 | 118° | 9535.62 | 5395.1 |
| 30′ | 1455.13 | 181.89 | 30′ | 3208.72 | 837.31 | 30′ | 5581.51 | 2269.3 | 30′ | 9630.55 | 5476.5 |
| 29° | 1481.77 | 188.51 | 59° | 3241.64 | 853.46 | 89° | 5630.44 | 2303.5 | 119° | 9726.89 | 5559.4 |
| 30′ | 1508.47 | 195.25 | 30′ | 3274.72 | 869.82 | 30′ | 5679.79 | 2338.2 | 30′ | 9824.67 | 5643.8 |
| 30° | 1535.24 | 202.12 | 60° | 3307.97 | 886.38 | 90° | 5729.58 | 2373.3 | 120° | 9923.92 | 5729.7 |
| 30′ | 1562.06 | 209.12 | 30′ | 3341.39 | 903.15 | 30′ | 5779.80 | 2408.9 | 30′ | 10,024.68 | 5817.0 |

## TABLE 5. CORRECTIONS FOR TANGENTS AND EXTERNALS

For railroad and highway curves laid out by the chord definition these corrections are to be added to the values found, using table on p. 208, in order to obtain the corrected tangents and external distances.

For Tangents Add *

| Central Angle | Degree of Curve | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° | 50° | 55° | 60° | 65° | 70° |
| 10° | .03 | .06 | .09 | .13 | .16 | .19 | .22 | .25 | .28 | .31 | .34 | .38 | .42 | .46 |
| 15° | .04 | .10 | .14 | .19 | .24 | .29 | .34 | .39 | .45 | .51 | .53 | .58 | .63 | .68 |
| 20° | .06 | .13 | .19 | .26 | .32 | .39 | .45 | .51 | .58 | .65 | .72 | .79 | .84 | .90 |
| 25° | .08 | .16 | .24 | .33 | .40 | .49 | .58 | .67 | .75 | .83 | .90 | .99 | 1.06 | 1.14 |
| 30° | .10 | .19 | .29 | .39 | .49 | .59 | .69 | .79 | .89 | .99 | 1.09 | 1.20 | 1.29 | 1.39 |
| 35° | .11 | .22 | .34 | .47 | .58 | .69 | .70 | .81 | .92 | 1.04 | 1.29 | 1.42 | 1.54 | 1.66 |
| 40° | .13 | .26 | .40 | .53 | .67 | .80 | .93 | 1.06 | 1.20 | 1.34 | 1.49 | 1.64 | 1.79 | 1.94 |
| 45° | .15 | .30 | .44 | .60 | .76 | .91 | 1.06 | 1.21 | 1.37 | 1.52 | 1.70 | 1.87 | 2.04 | 2.21 |
| 50° | .17 | .34 | .51 | .68 | .85 | 1.02 | 1.19 | 1.36 | 1.54 | 1.72 | 1.91 | 2.10 | 2.29 | 2.48 |
| 55° | .19 | .38 | .57 | .76 | .95 | 1.14 | 1.32 | 1.52 | 1.72 | 1.92 | 2.14 | 2.35 | 2.56 | 2.77 |
| 60° | .21 | .42 | .63 | .84 | 1.05 | 1.27 | 1.49 | 1.71 | 1.94 | 2.17 | 2.38 | 2.60 | 2.83 | 3.07 |
| 65° | .23 | .46 | .69 | .93 | 1.16 | 1.40 | 1.64 | 1.88 | 2.13 | 2.38 | 2.63 | 2.88 | 3.13 | 3.39 |
| 70° | .25 | .51 | .76 | 1.02 | 1.28 | 1.54 | 1.80 | 2.06 | 2.33 | 2.60 | 2.88 | 3.16 | 3.44 | 3.72 |
| 75° | .27 | .56 | .83 | 1.12 | 1.40 | 1.69 | 1.98 | 2.27 | 2.57 | 2.87 | 3.16 | 3.47 | 3.78 | 4.09 |
| 80° | .30 | .61 | .91 | 1.22 | 1.53 | 1.84 | 2.15 | 2.46 | 2.78 | 3.10 | 3.44 | 3.78 | 4.12 | 4.46 |
| 85° | .33 | .66 | 1.00 | 1.33 | 1.68 | 2.02 | 2.36 | 2.70 | 3.05 | 3.40 | 3.77 | 4.14 | 4.55 | 4.89 |
| 90° | .36 | .72 | 1.09 | 1.45 | 1.83 | 2.20 | 2.57 | 2.94 | 3.32 | 3.70 | 4.10 | 4.50 | 4.91 | 5.32 |
| 95° | .39 | .79 | 1.19 | 1.55 | 2.00 | 2.40 | 2.80 | 3.20 | 3.61 | 4.02 | 4.40 | 4.98 | 5.38 | 5.83 |
| 100° | .43 | .86 | 1.30 | 1.74 | 2.18 | 2.62 | 3.06 | 3.50 | 3.95 | 4.40 | 4.88 | 5.37 | 5.85 | 6.34 |
| 110° | .51 | 1.03 | 1.56 | 2.08 | 2.61 | 3.14 | 3.67 | 4.21 | 4.76 | 5.31 | 5.86 | 6.43 | 7.01 | 7.60 |
| 120° | .62 | 1.25 | 1.93 | 2.52 | 3.16 | 3.81 | 4.45 | 5.11 | 5.77 | 6.44 | 7.12 | 7.80 | 8.50 | 9.22 |

For Externals Add *

| Central Angle | Degree of Curve | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° | 50° | 55° | 60° | 65° | 70° |
| 10° | .001 | .003 | .004 | .006 | .007 | .008 | .009 | .011 | .012 | .014 | .015 | .017 | .018 | .020 |
| 15° | .003 | .007 | .010 | .014 | .018 | .023 | .027 | .029 | .032 | .035 | .039 | .043 | .047 | .051 |
| 20° | .006 | .011 | .017 | .022 | .028 | .034 | .038 | .045 | .051 | .057 | .063 | .070 | .076 | .083 |
| 25° | .009 | .018 | .027 | .036 | .046 | .056 | .065 | .074 | .083 | .093 | .106 | .120 | .127 | .135 |
| 30° | .013 | .025 | .038 | .051 | .065 | .078 | .090 | .103 | .116 | .129 | .149 | .170 | .179 | .188 |
| 35° | .018 | .035 | .054 | .072 | .086 | .109 | .131 | .153 | .175 | .197 | .213 | .230 | .247 | .264 |
| 40° | .023 | .046 | .070 | .093 | .117 | .141 | .172 | .203 | .234 | .265 | .277 | .290 | .315 | .341 |
| 45° | .030 | .060 | .093 | .119 | .153 | .184 | .216 | .254 | .289 | .325 | .351 | .378 | .411 | .445 |
| 50° | .037 | .075 | .116 | .151 | .189 | .227 | .266 | .305 | .345 | .384 | .425 | .467 | .508 | .550 |
| 55° | .046 | .093 | .142 | .188 | .236 | .283 | .332 | .381 | .420 | .479 | .530 | .582 | .641 | .700 |
| 60° | .056 | .112 | .168 | .225 | .283 | .340 | .398 | .457 | .516 | .575 | .636 | .697 | .774 | .851 |
| 65° | .067 | .135 | .204 | .273 | .343 | .412 | .483 | .554 | .625 | .697 | .711 | .845 | .922 | 1.01 |
| 70° | .080 | .159 | .240 | .321 | .403 | .485 | .568 | .652 | .735 | .819 | .906 | .994 | 1.08 | 1.17 |
| 75° | .095 | .182 | .286 | .383 | .480 | .578 | .678 | .777 | .877 | .977 | 1.07 | 1.18 | 1.29 | 1.39 |
| 80° | .110 | .220 | .332 | .445 | .558 | .671 | .787 | .903 | 1.02 | 1.13 | 1.25 | 1.38 | 1.50 | 1.62 |
| 85° | .128 | .259 | .391 | .524 | .657 | .790 | .926 | 1.06 | 1.20 | 1.34 | 1.47 | 1.62 | 1.76 | 1.91 |
| 90° | .149 | .299 | .450 | .603 | .756 | .910 | 1.07 | 1.22 | 1.38 | 1.54 | 1.70 | 1.87 | 2.03 | 2.20 |
| 95° | .174 | .350 | .522 | .706 | .985 | 1.06 | 1.25 | 1.43 | 1.62 | 1.80 | 1.99 | 2.18 | 2.38 | 2.58 |
| 100° | .200 | .401 | .604 | .809 | 1.01 | 1.22 | 1.43 | 1.64 | 1.85 | 2.06 | 2.28 | 2.50 | 2.73 | 2.96 |
| 110° | .268 | .536 | .806 | 1.08 | 1.35 | 1.63 | 1.91 | 2.20 | 2.48 | 2.76 | 3.05 | 3.35 | 3.66 | 3.96 |
| 120° | .360 | .721 | 1.08 | 1.45 | 1.82 | 2.19 | 2.57 | 2.95 | 3.33 | 3.72 | 4.11 | 4.50 | 4.91 | 5.32 |

* *Adapted from Dietzgen's Railroad Curve Tables by Eugene Dietzgen Co.*

## TABLE 6. DEFLECTIONS AND CHORD LENGTHS FOR CIRCULAR CURVES

### For Laying Out Arc Definition Curves By Measured Chords

| Degree of Curve | Radius | Deflection for Arc Length | | | | Chord for Arc Length | | |
|---|---|---|---|---|---|---|---|---|
| | | Deflection = arc length (0.3° of curve) | | | | Chord = 2*R* sin def. | | |
| | | 1′ | 25′ | 50′ | 100′ | 25′ | 50′ | 100′ |
| 0° 30′ | 11,459.16 | 0° 00.15′ | 0° 03.75′ | 0° 07.50′ | 0° 15.00′ | 25.00′ | 50.00′ | 100.00′ |
| 1° | 5,729.58 | 0° 00.30′ | 0° 07.50′ | 0° 15.00′ | 0° 30.00′ | 25.00′ | 50.00′ | 100.00′ |
| 30′ | 3,819.72 | 0° 00.45′ | 0° 11.25′ | 0° 22.50′ | 0° 45.00′ | 25.00′ | 50.00′ | 100.00′ |
| 2° | 2,864.79 | 0° 00.60′ | 0° 15.00′ | 0° 30.00′ | 1° 00.00′ | 25.00′ | 50.00′ | 100.00′ |
| 30′ | 2,291.83 | 0° 00.75′ | 0° 18.75′ | 0° 37.50′ | 1° 15.00′ | 25.00′ | 50.00′ | 99.99′ |
| 3° | 1,909.86 | 0° 00.90′ | 0° 22.50′ | 0° 45.00′ | 1° 30.00′ | 25.00′ | 50.00′ | 99.99′ |
| 30′ | 1,637.02 | 0° 01.05′ | 0° 26.25′ | 0° 52.50′ | 1° 45.00′ | 25.00′ | 50.00′ | 99.98′ |
| 4° | 1,432.40 | 0° 01.20′ | 0° 30.00′ | 1° 00.00′ | 2° 00.00′ | 25.00′ | 50.00′ | 99.98′ |
| 30′ | 1,273.24 | 0° 01.35′ | 0° 33.75′ | 1° 07.50′ | 2° 15.00′ | 25.00′ | 50.00′ | 99.97′ |
| 5° | 1,145.92 | 0° 01.50′ | 0° 37.50′ | 1° 15.00′ | 2° 30.00′ | 25.00′ | 50.00′ | 99.97′ |
| 30′ | 1,041.74 | 0° 01.65′ | 0° 41.25′ | 1° 22.50′ | 2° 45.00′ | 25.00′ | 50.00′ | 99.96′ |
| 6° | 954.93 | 0° 01.80′ | 0° 45.00′ | 1° 30.00′ | 3° 00.00′ | 25.00′ | 50.00′ | 99.95′ |
| 30′ | 881.47 | 0° 01.95′ | 0° 48.75′ | 1° 37.50′ | 3° 15.00′ | 25.00′ | 50.00′ | 99.95′ |
| 7° | 818.51 | 0° 02.10′ | 0° 52.50′ | 1° 45.00′ | 3° 30.00′ | 25.00′ | 50.00′ | 99.94′ |
| 30′ | 763.94 | 0° 02.25′ | 0° 56.25′ | 1° 52.50′ | 3° 45.00′ | 25.00′ | 49.99′ | 99.93′ |
| 8° | 716.20 | 0° 02.40′ | 1° 00.00′ | 2° 00.00′ | 4° 00.00′ | 25.00′ | 49.99′ | 99.92′ |
| 30′ | 674.07 | 0° 02.55′ | 1° 03.75′ | 2° 07.50′ | 4° 15.00′ | 25.00′ | 49.99′ | 99.91′ |
| 9° | 636.62 | 0° 02.70′ | 1° 07.50′ | 2° 15.00′ | 4° 30.00′ | 25.00′ | 49.99′ | 99.90′ |
| 30′ | 603.11 | 0° 02.85′ | 1° 11.25′ | 2° 22.50′ | 4° 45.00′ | 25.00′ | 49.99′ | 99.89′ |
| 10° | 572.96 | 0° 03.00′ | 1° 15.00′ | 2° 30.00′ | 5° 00.00′ | 25.00′ | 49.98′ | 99.87′ |
| 11° | 520.87 | 0° 03.30′ | 1° 22.50′ | 2° 45.00′ | 5° 30.00′ | 25.00′ | 49.98′ | 99.85′ |
| 12° | 477.46 | 0° 03.60′ | 1° 30.00′ | 3° 00.00′ | 6° 00.00′ | 25.00′ | 49.98′ | 99.82′ |
| 13° | 440.74 | 0° 03.90′ | 1° 37.50′ | 3° 15.00′ | 6° 30.00′ | 25.00′ | 49.97′ | 99.79′ |
| 14° | 409.26 | 0° 04.20′ | 1° 45.00′ | 3° 30.00′ | 7° 00.00′ | 25.00′ | 49.97′ | 99.75′ |
| 15° | 381.97 | 0° 04.50′ | 1° 52.50′ | 3° 45.00′ | 7° 30.00′ | 25.00′ | 49.96′ | 99.72′ |
| 16° | 358.10 | 0° 04.80′ | 2° 00.00′ | 4° 00.00′ | 8° 00.00′ | 25.00′ | 49.96′ | 99.68′ |
| 17° | 337.03 | 0° 05.10′ | 2° 07.50′ | 4° 15.00′ | 8° 30.00′ | 25.00′ | 49.95′ | 99.63′ |
| 18° | 318.31 | 0° 05.40′ | 2° 15.00′ | 4° 30.00′ | 9° 00.00′ | 24.99′ | 49.95′ | 99.59′ |
| 19° | 301.56 | 0° 05.70′ | 2° 22.50′ | 4° 45.00′ | 9° 30.00′ | 24.99′ | 49.94′ | 99.54′ |
| 20° | 286.48 | 0° 06.00′ | 2° 30.00′ | 5° 00.00′ | 10° 00.00′ | 24.99′ | 49.94′ | 99.49′ |
| 21° | 272.84 | 0° 06.30′ | 2° 37.50′ | 5° 15.00′ | 10° 30.00′ | 24.99′ | 49.93′ | 99.44′ |
| 22° | 260.44 | 0° 06.60′ | 2° 45.00′ | 5° 30.00′ | 11° 00.00′ | 24.99′ | 49.92′ | 99.39′ |
| 23° | 249.11 | 0° 06.90′ | 2° 52.50′ | 5° 45.00′ | 11° 30.00′ | 24.99′ | 49.92′ | 99.33′ |
| 24° | 238.73 | 0° 07.20′ | 3° 00.00′ | 6° 00.00′ | 12° 00.00′ | 24.99′ | 49.91′ | 99.27′ |
| 38° 12′ | 150 | 0° 11.45′ | 4° 46.48′ | 9° 32.96′ | 19° 05.92′ | 24.97′ | 49.77′ | 98.16′ |
| 28° 39′ | 200 | 0° 08.59′ | 3° 34.86′ | 7° 09.72′ | 14° 19.44′ | 24.98′ | 49.87′ | 98.96′ |
| 25° 28′ | 225 | 0° 07.64′ | 3° 10.99′ | 6° 21.97′ | 12° 43.94′ | 24.99′ | 49.90′ | 99.18′ |
| 22° 55′ | 250 | 0° 06.88′ | 2° 51.89′ | 5° 43.78′ | 11° 27.55′ | 24.99′ | 49.92′ | 99.34′ |
| 20° 50′ | 275 | 0° 06.25′ | 2° 36.26′ | 5° 12.52′ | 10° 25.04′ | 24.99′ | 49.93′ | 99.45′ |
| 19° 06′ | 300 | 0° 05.73′ | 2° 23.24′ | 4° 46.48′ | 9° 32.96′ | 24.99′ | 49.94′ | 99.54′ |
| 17° 38′ | 325 | 0° 05.29′ | 2° 12.22′ | 4° 24.44′ | 8° 48.88′ | 24.99′ | 49.95′ | 99.61′ |
| 16° 22′ | 350 | 0° 04.91′ | 2° 02.78′ | 4° 05.55′ | 8° 11.11′ | 25.00′ | 49.96′ | 99.66′ |
| 15° 17′ | 375 | 0° 04.58′ | 1° 54.59′ | 3° 49.18′ | 7° 38.37′ | 25.00′ | 49.96′ | 99.70′ |
| 14° 19′ | 400 | 0° 04.30′ | 1° 47.43′ | 3° 34.86′ | 7° 09.72′ | 25.00′ | 49.97′ | 99.74′ |
| 12° 44′ | 450 | 0° 03.82′ | 1° 35.49′ | 3° 10.99′ | 6° 21.97′ | 25.00′ | 49.97′ | 99.79′ |
| 11° 28′ | 500 | 0° 03.44′ | 1° 25.94′ | 2° 51.89′ | 5° 43.77′ | 25.00′ | 49.98′ | 99.83′ |
| 10° 25′ | 550 | 0° 03.13′ | 1° 18.13′ | 2° 36.26′ | 5° 12.52′ | 25.00′ | 49.98′ | 99.86′ |
| 9° 33′ | 600 | 0° 02.86′ | 1° 11.62′ | 2° 23.24′ | 4° 46.48′ | 25.00′ | 49.99′ | 99.89′ |
| 8° 50′ | 650 | 0° 02.64′ | 1° 06.11′ | 2° 12.22′ | 4° 24.44′ | 25.00′ | 49.99′ | 99.90′ |
| 8° 11′ | 700 | 0° 02.46′ | 1° 01.39′ | 2° 02.78′ | 4° 05.55′ | 25.00′ | 49.99′ | 99.92′ |
| 7° 38′ | 750 | 0° 02.29′ | 0° 57.30′ | 1° 54.59′ | 3° 49.18′ | 25.00′ | 50.00′ | 99.93′ |
| 7° 10′ | 800 | 0° 02.15′ | 0° 53.71′ | 1° 47.43′ | 3° 34.86′ | 25.00′ | 50.00′ | 99.93′ |
| 6° 44′ | 850 | 0° 02.02′ | 0° 50.56′ | 1° 41.11′ | 3° 22.22′ | 25.00′ | 50.00′ | 99.94′ |
| 6° 22′ | 900 | 0° 01.91′ | 0° 47.75′ | 1° 35.49′ | 3° 10.99′ | 25.00′ | 50.00′ | 99.95′ |
| 6° 02′ | 950 | 0° 01.81′ | 0° 45.23′ | 1° 30.47′ | 3° 00.93′ | 25.00′ | 50.00′ | 99.95′ |
| 5° 44′ | 1000 | 0° 01.72′ | 0° 42.97′ | 1° 25.94′ | 2° 51.89′ | 25.00′ | 50.00′ | 99.96′ |

Deflection for curves of even radii = $\frac{1718.873}{R}$ arc length.

# TABLE 7. LENGTHS OF CIRCULAR ARCS FOR UNIT RADIUS *

By the use of this table, the length of any arc may be found if the length of the radius and the angle of the segment are known. EXAMPLE. *Required:* The length of arc of segment of 32° 15′ 27″ with radius of 24 ft. 3 in.

From table: Length of arc (radius 1) for 32° = 0.5585054
15′ = 0.0043633
27″ = 0.0001309

0.5629996

0.5629996 × 24.25 (length of radius) = 13.65 ft.

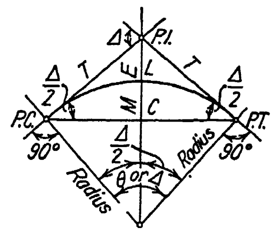
| Degrees | | | | | | Minutes | | Seconds | |
|---|---|---|---|---|---|---|---|---|---|
| ° | | ° | | ° | | ′ | | ″ | |
| 1 | .017 4533 | 61 | 1.064 6508 | 121 | 2.111 8484 | 1 | .000 2909 | 1 | .000 0048 |
| 2 | .034 9066 | 62 | 1.082 1041 | 122 | 2.129 3017 | 2 | .000 5818 | 2 | .000 0097 |
| 3 | .052 3599 | 63 | 1.099 5574 | 123 | 2.146 7550 | 3 | .000 8727 | 3 | .000 0145 |
| 4 | .069 8132 | 64 | 1.117 0107 | 124 | 2.164 2083 | 4 | .001 1636 | 4 | .000 0194 |
| 5 | .087 2665 | 65 | 1.134 4640 | 125 | 2.181 6616 | 5 | .001 4544 | 5 | .000 0242 |
| 6 | .104 7198 | 66 | 1.151 9173 | 126 | 2.199 1149 | 6 | .001 7453 | 6 | .000 0291 |
| 7 | .122 1730 | 67 | 1.169 3706 | 127 | 2.216 5682 | 7 | .002 0362 | 7 | .000 0339 |
| 8 | .139 6263 | 68 | 1.186 8239 | 128 | 2.234 0214 | 8 | .002 3271 | 8 | .000 0388 |
| 9 | .157 0796 | 69 | 1.204 2772 | 129 | 2.251 4747 | 9 | .002 6180 | 9 | .000 0436 |
| 10 | .174 5329 | 70 | 1.221 7305 | 130 | 2.268 9280 | 10 | .002 9089 | 10 | .000 0485 |
| 11 | .191 9862 | 71 | 1.239 1838 | 131 | 2.286 3813 | 11 | .003 1998 | 11 | .000 0533 |
| 12 | .209 4395 | 72 | 1.256 6371 | 132 | 2.303 8346 | 12 | .003 4907 | 12 | .000 0582 |
| 13 | .226 8928 | 73 | 1.274 0904 | 133 | 2.321 2879 | 13 | .003 7815 | 13 | .000 0630 |
| 14 | .244 3461 | 74 | 1.291 5436 | 134 | 2.338 7412 | 14 | .004 0724 | 14 | .000 0679 |
| 15 | .261 7994 | 75 | 1.308 9969 | 135 | 2.356 1945 | 15 | .004 3633 | 15 | .000 0727 |
| 16 | .279 2527 | 76 | 1.326 4502 | 136 | 2.373 6478 | 16 | .004 6542 | 16 | .000 0776 |
| 17 | .296 7060 | 77 | 1.343 9035 | 137 | 2.391 1011 | 17 | .004 9451 | 17 | .000 0824 |
| 18 | .314 1593 | 78 | 1.361 3568 | 138 | 2.408 5544 | 18 | .005 2360 | 18 | .000 0873 |
| 19 | .331 6126 | 79 | 1.378 8101 | 139 | 2.426 0077 | 19 | .005 5269 | 19 | .000 0921 |
| 20 | .349 0659 | 80 | 1.396 2634 | 140 | 2.443 4610 | 20 | .005 8178 | 20 | .000 0970 |
| 21 | .366 5191 | 81 | 1.413 7167 | 141 | 2.460 9142 | 21 | .006 1087 | 21 | .000 1018 |
| 22 | .383 9724 | 82 | 1.431 1700 | 142 | 2.478 3675 | 22 | .006 3995 | 22 | .000 1067 |
| 23 | .401 4257 | 83 | 1.448 6233 | 143 | 2.495 8208 | 23 | .006 6904 | 23 | .000 1115 |
| 24 | .418 8790 | 84 | 1.466 0766 | 144 | 2.513 2741 | 24 | .006 9813 | 24 | .000 1164 |
| 25 | .436 3323 | 85 | 1.483 5299 | 145 | 2.530 7274 | 25 | .007 2722 | 25 | .000 1212 |
| 26 | .453 7856 | 86 | 1.500 9832 | 146 | 2.548 1807 | 26 | .007 5631 | 26 | .000 1261 |
| 27 | .471 2389 | 87 | 1.518 4364 | 147 | 2.565 6340 | 27 | .007 8540 | 27 | .000 1309 |
| 28 | .488 6922 | 88 | 1.535 8897 | 148 | 2.583 0873 | 28 | .008 1449 | 28 | .000 1357 |
| 29 | .506 1455 | 89 | 1.553 3430 | 149 | 2.600 5406 | 29 | .008 4358 | 29 | .000 1406 |
| 30 | .523 5988 | 90 | 1.570 7963 | 150 | 2.617 9939 | 30 | .008 7266 | 30 | .000 1454 |
| 31 | .541 0521 | 91 | 1.588 2496 | 151 | 2.635 4472 | 31 | .009 0175 | 31 | .000 1503 |
| 32 | .558 5054 | 92 | 1.605 7029 | 152 | 2.652 9005 | 32 | .009 3084 | 32 | .000 1551 |
| 33 | .575 9587 | 93 | 1.623 1562 | 153 | 2.670 3538 | 33 | .009 5993 | 33 | .000 1600 |
| 34 | .593 4119 | 94 | 1.640 6095 | 154 | 2.687 8070 | 34 | .009 8902 | 34 | .000 1648 |
| 35 | .610 8652 | 95 | 1.658 0628 | 155 | 2.705 2603 | 35 | .010 1811 | 35 | .000 1697 |
| 36 | .628 3185 | 96 | 1.675 5161 | 156 | 2.722 7136 | 36 | .010 4720 | 36 | .000 1745 |
| 37 | .645 7718 | 97 | 1.692 9694 | 157 | 2.740 1669 | 37 | .010 7629 | 37 | .000 1794 |
| 38 | .663 2251 | 98 | 1.710 4227 | 158 | 2.757 6202 | 38 | .011 0538 | 38 | .000 1842 |
| 39 | .680 6784 | 99 | 1.727 8760 | 159 | 2.775 0735 | 39 | .011 3446 | 39 | .000 1891 |
| 40 | .698 1317 | 100 | 1.745 3293 | 160 | 2.792 5268 | 40 | .011 6355 | 40 | .000 1939 |
| 41 | .715 5850 | 101 | 1.762 7825 | 161 | 2.809 9801 | 41 | .011 9264 | 41 | .000 1988 |
| 42 | .733 0383 | 102 | 1.780 2358 | 162 | 2.827 4334 | 42 | .012 2173 | 42 | .000 2036 |
| 43 | .750 4916 | 103 | 1.797 6891 | 163 | 2.844 8867 | 43 | .012 5082 | 43 | .000 2085 |
| 44 | .767 9449 | 104 | 1.815 1424 | 164 | 2.862 3400 | 44 | .012 7991 | 44 | .000 2133 |
| 45 | .785 3982 | 105 | 1.832 5957 | 165 | 2.879 7933 | 45 | .013 0900 | 45 | .000 2182 |
| 46 | .802 8515 | 106 | 1.850 0490 | 166 | 2.897 2466 | 46 | .013 3809 | 46 | .000 2230 |
| 47 | .820 3047 | 107 | 1.867 5023 | 167 | 2.914 6999 | 47 | .013 6717 | 47 | .000 2279 |
| 48 | .837 7580 | 108 | 1.884 9556 | 168 | 2.932 1531 | 48 | .013 9626 | 48 | .000 2327 |
| 49 | .855 2113 | 109 | 1.902 4089 | 169 | 2.949 6064 | 49 | .014 2535 | 49 | .000 2376 |
| 50 | .872 6646 | 110 | 1.919 8622 | 170 | 2.967 0597 | 50 | .014 5444 | 50 | .000 2424 |
| 51 | .890 1179 | 111 | 1.937 3155 | 171 | 2.984 5130 | 51 | .014 8353 | 51 | .000 2473 |
| 52 | .907 5712 | 112 | 1.954 7688 | 172 | 3.001 9663 | 52 | .015 1262 | 52 | .000 2521 |
| 53 | .925 0245 | 113 | 1.972 2221 | 173 | 3.019 4196 | 53 | .015 4171 | 53 | .000 2570 |
| 54 | .942 4778 | 114 | 1.989 6753 | 174 | 3.036 8729 | 54 | .015 7080 | 54 | .000 2618 |
| 55 | .959 9311 | 115 | 2.007 1286 | 175 | 3.054 3262 | 55 | .015 9989 | 55 | .000 2666 |
| 56 | .977 3844 | 116 | 2.024 5819 | 176 | 3.071 7795 | 56 | .016 2897 | 56 | .000 2715 |
| 57 | .994 8377 | 117 | 2.042 0352 | 177 | 3.089 2328 | 57 | .016 5806 | 57 | .000 2763 |
| 58 | 1.012 2910 | 118 | 2.059 4885 | 178 | 3.106 6861 | 58 | .016 8715 | 58 | .000 2812 |
| 59 | 1.029 7443 | 119 | 2.076 9418 | 179 | 3.124 1394 | 59 | .017 1624 | 59 | .000 2860 |
| 60 | 1.047 1976 | 120 | 2.094 3951 | 180 | 3.141 5927 | 60 | .017 4533 | 60 | .000 2909 |

* *From War Department, Surveying Tables.*

## TABLE 8. METRIC CURVES

| Deflection Angle 20-m. Chord | Radius in Meters | Log of Radius | Mid. Ordinate | Tangent Offset | Degree of Equivalent U. S. Curve | Deflection Angle 20-m. Chord |
|---|---|---|---|---|---|---|
| 0° 10′ | 3437.75 | 3.536274 | .015 | 0.058 | 0° 30′ | 0° 10′ |
| 20 | 1718.89 | 3.235246 | .029 | 0.116 | 1 01 | 20 |
| 30 | 1145.93 | 3.059158 | .044 | 0.175 | 1 31 | 30 |
| 40 | 859.46 | 2 934224 | .058 | 0.233 | 2 02 | 40 |
| 50 | 687.57 | 2.837319 | .073 | 0.291 | 2 32 | 50 |
| 1 00 | 572.99 | 2.758145 | .087 | 0.349 | 3 03 | 1 00 |
| 10 | 491.14 | 2.691206 | .102 | 0.407 | 3 33 | 10 |
| 20 | 429.76 | 2.633223 | .116 | 0.465 | 4 04 | 20 |
| 30 | 382.02 | 2.582081 | .131 | 0.524 | 4 34 | 30 |
| 40 | 343.82 | 2.536335 | .145 | 0.582 | 5 05 | 40 |
| 50 | 312.58 | 2.494955 | .160 | 0.640 | 5 35 | 50 |
| 2 00 | 286.54 | 2.457181 | .175 | 0.698 | 6 06 | 2 00 |
| 10 | 264.51 | 2.422434 | .189 | 0.756 | 6 36 | 10 |
| 20 | 245.62 | 2.390266 | .204 | 0.814 | 7 07 | 20 |
| 30 | 229.26 | 2.360320 | .218 | 0.872 | 7 37 | 30 |
| 40 | 214.94 | 2.332311 | .233 | 0.931 | 8 08 | 40 |
| 50 | 202.30 | 2.306002 | .247 | 0.989 | 8 38 | 50 |
| 3 00 | 191.07 | 2.281200 | .262 | 1.047 | 9 09 | 3 00 |
| 10 | 181.03 | 2.257741 | .276 | 1.105 | 9 40 | 10 |
| 20 | 171.98 | 2.235489 | .291 | 1.163 | 10 10 | 20 |
| 30 | 163.80 | 2.214325 | .306 | 1.221 | 10 41 | 30 |
| 40 | 156.37 | 2.194148 | .320 | 1.279 | 11 11 | 40 |
| 50 | 149.58 | 2.174870 | .335 | 1.337 | 11 42 | 50 |
| 4 00 | 143.36 | 2.156416 | .349 | 1.395 | 12 12 | 4 00 |
| 10 | 137.63 | 2.138717 | .364 | 1.453 | 12 43 | 10 |
| 20 | 132.35 | 2.121715 | .378 | 1.511 | 13 13 | 20 |
| 30 | 127.45 | 2.105357 | .393 | 1.569 | 13 44 | 30 |
| 40 | 122.91 | 2.089596 | .407 | 1.627 | 14 15 | 40 |
| 50 | 118.68 | 2.074391 | .422 | 1.685 | 14 45 | 50 |
| 5 00 | 114.737 | 2.059704 | .437 | 1.743 | 15 16 | 5 00 |
| 10 | 111.045 | 2.045501 | .451 | 1.801 | 15 47 | 10 |
| 20 | 107.585 | 2.031751 | .466 | 1.859 | 16 17 | 20 |
| 30 | 104.334 | 2.018427 | .480 | 1.917 | 16 48 | 30 |
| 40 | 101.275 | 2.005503 | .495 | 1.975 | 17 19 | 40 |
| 50 | 98.391 | 1.992956 | .509 | 2.033 | 17 49 | 50 |
| 6 00 | 95.668 | 1.980765 | .524 | 2.091 | 18 20 | 6 00 |
| 10 | 93.092 | 1.968911 | .539 | 2.148 | 18 51 | 10 |
| 20 | 90.652 | 1.957375 | .553 | 2.206 | 19 21 | 20 |
| 30 | 88.337 | 1.946141 | .568 | 2.264 | 19 52 | 30 |
| 40 | 86.138 | 1.935194 | .582 | 2.322 | 20 23 | 40 |
| 50 | 84.047 | 1.924520 | .597 | 2.380 | 20 54 | 50 |
| 7 00 | 82.055 | 1.914105 | .612 | 2.437 | 21 24 | 7 00 |
| 10 | 80.156 | 1.903938 | .626 | 2.495 | 21 55 | 10 |
| 20 | 78.344 | 1.894008 | .641 | 2.553 | 22 26 | 20 |
| 30 | 76.613 | 1.884302 | .655 | 2.611 | 22 57 | 30 |
| 40 | 74.957 | 1.874813 | .670 | 2.668 | 23 28 | 40 |
| 50 | 73.372 | 1.865530 | .685 | 2.726 | 23 59 | 50 |
| 8 00 | 71.853 | 1.856445 | .699 | 2.783 | 24 29 | 8 00 |
| 10 | 70.396 | 1.847549 | .714 | 2.841 | 25 00 | 10 |
| 20 | 68.998 | 1.838836 | .729 | 2.899 | 25 31 | 20 |
| 30 | 67.655 | 1.830298 | .743 | 2.956 | 26 02 | 30 |
| 40 | 66.363 | 1.821928 | .758 | 3.014 | 26 33 | 40 |
| 50 | 65.121 | 1.813720 | .772 | 3.071 | 27 04 | 50 |
| 9 00 | 63.925 | 1.805668 | .787 | 3.129 | 27 35 | 9 00 |
| 10 | 62.772 | 1.797766 | .802 | 3.186 | 28 06 | 10 |
| 20 | 61.661 | 1.790008 | .816 | 3.244 | 28 37 | 20 |
| 30 | 60.589 | 1.782391 | .831 | 3.301 | 29 08 | 30 |
| 40 | 59.554 | 1.774908 | .846 | 3.358 | 29 39 | 40 |
| 50 | 58.554 | 1.767556 | .860 | 3.416 | 30 10 | 50 |
| 10° 00′ | 57.588 | 1.760330 | .875 | 3.473 | 30 41 | 10° 00′ |

*Note.* The degree of curve is not usually used for the curves involved in street intersections, curbs, road intersections, runway and taxiway fillets, and turnarounds, traffic circles, rotaries, cloverleafs, etc. These curves are defined by the radius $R$, and central angle, $\Delta$ or $\theta$.



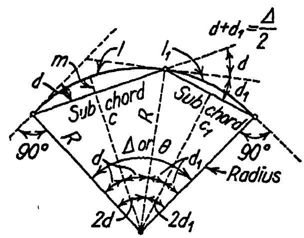
Short-radius Curve

NOTATION

$T$ = tangent length P.C. or P.T. to P.I.
$L$ = arc length P.C. to P.T.
$l$ = arc length for any subchord
$C$ = long chord P.C. to P.T.
$c$ = any subchord.
$d$ = deflection to any point.
$\Delta$ = central angle in degrees.
$\theta$ = central angle in radians.

$$\text{One radian} = \frac{360^\circ}{2\pi} = \frac{180^\circ}{\pi} = 57.2958^\circ = 57^\circ\,17'\,44.8''$$

$\pi$ = 3.14159.
$M$ = mid. ordinate; $m$ for subchords.
$E$ = external; $e$ for subchords.



Subchords and Deflections

$$R = \frac{L}{\theta} = \frac{L \cdot 180/\Delta}{\pi} = \frac{L}{\Delta}57.2958 = T \cdot \cot\frac{\Delta}{2} = \frac{C}{2\sin\Delta/2}.$$

$$\frac{4M^2 + C^2}{8M} = \frac{M^2 + (C/2)^2}{2M}.$$

$$L = R\theta = \frac{\Delta R\pi}{180} = 0.017453\Delta R = \text{circum.}\cdot\frac{\Delta}{360}.$$

$$T = R \cdot \tan\frac{\Delta}{2} = E \cdot \cot\frac{\Delta}{4} = \frac{C}{2\cos\Delta/2}.$$

$$C = 2R \cdot \sin\frac{\Delta}{2} = 2T \cdot \cos\frac{\Delta}{2} = 2\sqrt{M(2R - M)}$$

$$M = R \cdot \text{vers}\frac{\Delta}{2} = E \cdot \cos\frac{\Delta}{2} = R\left(1 - \cos\frac{\Delta}{2}\right).$$

$$E = R \cdot \text{exsec}\frac{\Delta}{2} = T \cdot \tan\frac{\Delta}{4} = \frac{R}{\cos\Delta/2} - R.$$

$$\Delta = \frac{180L}{\pi R} = 57.2958\frac{L}{R} = \theta \cdot 57.2958.$$

$$\theta = \frac{L}{R} = \frac{\Delta\pi}{180} = \Delta \cdot 0.017453.$$

$$\sin\frac{\Delta}{2} = \frac{C}{2R}; \quad \cos\frac{\Delta}{2} = \frac{R-M}{R} = \frac{C}{2T}; \quad \tan\frac{\Delta}{2} = \frac{T}{R}$$

Subcord $= 2R \cdot \sin d = 2(R - M) \cdot \tan d.$

$d$(in minutes) $= 1718.873 \dfrac{l}{R}\cdot$ Radius $= \dfrac{C}{2 \sin d}.$

Length $= \dfrac{\pi R d}{90} = 0.034906Rd$($d$ in degrees).

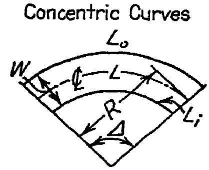
Mid. ordinate $= R(1 - \cos d) = 2R \cdot \sin^2 \dfrac{d}{2}$

Tan $d = \dfrac{\frac{1}{2}C}{R - m}$; $\sin d = \dfrac{\frac{1}{2}C}{R}$

Excess of $l$ over $c = l - c = l - 2R \cdot \sin d.$

Sum of deflection angles, $d_1 + d_2 + \cdots d_n = \dfrac{\Delta}{2}$

Concentric Curves




$$L_0 = \frac{R + W/2}{R} L$$

$$L_i = \frac{R - W/2}{R} L$$

$$L_0 - L_i = 0.017453W \cdot \Delta$$

$$= W \cdot L/R$$

$$\text{Area} = L \cdot W$$

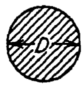
EXAMPLE. *Given.* $R = 50'$; $\Delta = 110°(\theta = 1.9195)$; $l = 50'$.
*Required.* $L$, $l_1$, $d$, $d_1$, $c$, and $c_1$.
*Solution.*
$L = 50 \times 1.9195 = 95.98'$; $l_1 = 95.98 - 50 = 45.98'$.
$d = 1718.873 \times 50/50 = 28° \, 39'$.
$d_1 = 1718.873 \times \dfrac{45.98}{50} = 26° \, 21'$.
$c = 2R \sin 28° \, 39' = 47.946'$.
$c_1 = 2R \sin 26° \, 21' = 44.385'$.

# TABLE 9. DEFLECTIONS ($d$) AND MIDDLE ORDINATES ($m$) FOR SUBCHORDS *

| X | Chord \ Radius | 10′ | 12′ | 15′ | 18′ | 20′ | 25′ | 30′ | 35′ | 40′ | 45′ | 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 120′ | 150′ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deflection | 5′ | 14° 29′ | 12° 01′ | 9° 36′ | 7° 59′ | 7° 11′ | 5° 44′ | 4° 47′ | 4° 06′ | 3° 35′ | 3° 11′ | 2° 52′ | 2° 23′ | 2° 03′ | 1° 47′ | 1° 35′ | 1° 26′ | 1° 12′ | 0° 57′ |
| | 10′ | 30° 00′ | 24° 37′ | 19° 28′ | 16° 08′ | 14° 29′ | 11° 32′ | 9° 36′ | 8° 13′ | 7° 11′ | 6° 23′ | 5° 44′ | 4° 47′ | 4° 06′ | 3° 35′ | 3° 11′ | 2° 52′ | 2° 23′ | 1° 55′ |
| | 20′ | | 56° 26′ | 41° 49′ | 33° 45′ | 30° 00′ | 23° 35′ | 19° 28′ | 16° 36′ | 14° 29′ | 12° 50′ | 11° 32′ | 9° 36′ | 8° 13′ | 7° 11′ | 6° 23′ | 5° 44′ | 4° 47′ | 3° 49′ |
| | 25′ | | | 56° 27′ | 43° 59′ | 38° 41′ | 30° 00′ | 24° 37′ | 20° 55′ | 18° 13′ | 16° 08′ | 14° 29′ | 12° 01′ | 10° 17′ | 8° 59′ | 7° 59′ | 7° 11′ | 5° 59′ | 4° 47′ |
| | 50′ | | | | | | | 56° 27′ | 45° 35′ | 38° 41′ | 33° 45′ | 30° 00′ | 24° 37′ | 20° 55′ | 18° 13′ | 16° 08′ | 14° 29′ | 12° 01′ | 9° 36′ |
| M. | 10′ | 1.34 | 1.09 | 0.86 | 0.71 | 0.64 | 0.51 | 0.42 | 0.36 | 0.31 | 0.28 | 0.25 | 0.21 | 0.18 | 0.16 | 0.14 | 0.13 | 0.10 | 0.08 |
| | 20′ | | 5.37 | 3.82 | 3.03 | 2.68 | 2.09 | 1.72 | 1.46 | 1.27 | 1.12 | 1.01 | 0.84 | 0.72 | 0.63 | 0.56 | 0.50 | 0.42 | 0.33 |

* *Adapted from Lefax Society, Inc., Philadelphia, Pa.*

Circle



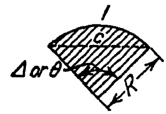

$$\text{Area} = \pi R^2 = \frac{\pi D^2}{4}$$

$$\text{Circumference} = 2\pi R = \pi D.$$

$$R = \frac{\text{Cir.}}{2\pi} = \frac{D}{2} = \sqrt{\frac{\text{Area}}{\pi}}$$

$$D = 2R = \text{cir.}/\pi$$

Sector of Circle

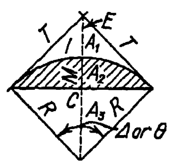



$$\text{Area} = 0.008727R^2\Delta$$
$$= \frac{l}{2}\cdot R = \pi R^2 \frac{\Delta}{360}$$
$$= R^2\cdot\frac{\theta}{2}$$

when

$$\Delta = 90°: A = 0.3927C^2;\ 0.7854R^2$$

Segment of Circle




$$A_1 = R^2\left(\tan\frac{\Delta}{2} - \frac{\Delta\pi}{360}\right) = R\left(T - \frac{l}{2}\right).$$

$$A_2 = \frac{lR - c(R - M)}{2} = \left(\pi R^2 \frac{\Delta}{360}\right) - \left[\left(R \sin\frac{\Delta}{2}\right)\left(R \cos\frac{\Delta}{2}\right)\right].$$

$$A_2 = \left(\pi R^2 \frac{\Delta}{360}\right) - \tfrac{1}{2}c(R - M)$$

$$A_2 = \tfrac{2}{3}\, Mc \begin{cases} \text{Correct for parabolic segment, approximate} \\ \quad\text{for circular segment.} \end{cases}$$

$$A_2 = \tfrac{1}{2}R^2(\theta - \sin\Delta) = \tfrac{2}{3}Mc + \frac{M^3}{2c}$$

$$A_3 = \tfrac{1}{2}R^2 \sin\Delta = \tfrac{1}{2}c(R - M) = \left(R \sin\frac{\Delta}{2}\right)\left(R \cos\frac{\Delta}{2}\right).$$

When $\Delta = 90°$: $A_1 = 0.2146R^2$

$$= 1.2594E^2$$

FIG. 9. Formulas for areas.

## TRANSITION CURVES *

### FORMULAS

$$T_s = (R_c + p)\tan\frac{\Delta}{2} + k.$$

$$E_s = (R_c + p)\operatorname{exsec}\frac{\Delta}{2} + p = \frac{R_c + p}{\cos\frac{\Delta}{2}} - R_c.$$

$$P = y_c - R_c(1 - \cos\theta_s) = \frac{y_c}{4}\text{ (approx.)}.$$

$$k = x_c - R_c\sin\theta_s = \frac{L_s}{2}\text{ (approx.)}.$$

$$\theta_s = \frac{L_sD_c}{200};\ \theta = \left(\frac{L}{L_s}\right)^2\theta_s.$$

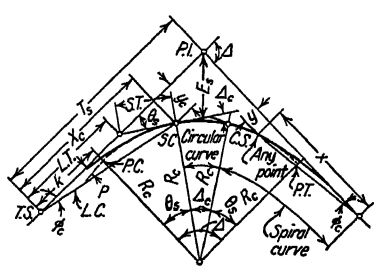
$$\theta = \frac{L^2D_c}{200\ L_s}.$$

$$L_c = \frac{100\ \Delta_c}{D_c};\ \text{L.C.} = \frac{X_c}{\cos\phi_c}.$$

$$\Delta_c = \Delta - \frac{L_sD_c}{100}.$$

$$D = \frac{L}{L_s}D_c.$$

$$D_c = \frac{200\ \theta_s}{L_s}.$$




*Note.* At the P.C. the spiral approximately bisects $P$.

### OFFSETS TO $x$ AND $y$

$$y = \frac{L^3}{L_s}y_c = L(y \text{ for } L_s = 1).$$

$$y_c = L_s(y \text{ for } L_s = 1).$$

$$x = L(x \text{ for } L_s = 1);$$

$$x_c = L_s(x \text{ for } L_s = 1).$$

### OFFSETS TO ¼ POINTS

$y$ at ¼ point $= y_c/4^3$

$y$ at ½ point $= y_c/2^3 = P/2$ (approx.)

$y$ at ¾ point $= y_c/(4/3)^3$

### TOTAL LENGTH OF CURVE

$$T_s \text{ to S.T.} = 2L_s + 100\frac{\Delta_c}{D_c}$$

$$\phi_c = \theta/3 - c;\ \phi = (L/Ls)^2\phi_c.$$

FIG. 10. Circular curves with spiral transitions.

* *Adapted from Transition Curves for Highways by Joseph Barnett, P.R.A.*

*Notes for Fig. 10.* With $L_s$ given or selected from Table 11 below, $p$, $k$, $x$, $y$, L.T., S.T., and L.C. may be computed for any spiral by multiplying functions for $L_s = 1$ in Table 12, p. 224, by $L_s$ or $L$ in feet. Interpolate for values of $\theta$ or $\theta_s$ between even degrees. For circular curve layout see pp. 202, 203, 204.

Circular curve may be omitted and curve made transitional throughout in which case S.C. and C.S. coincide at S.C.S., $\theta = \Delta/2$, $\Delta_c = 0$, and $T_s$ and $E_s$ are computed from Table 13, p. 225.

## Notation

$R_c$ = radius of the circular curve.

$P$ = offset distance from tangent to the P.C. of the circular curve produced.

$k$ = distance from T.S. to P.C. along tangent.

$T_s$ = tangent distance.

$E_s$ = external distance.

$x_c, y_c$ = coordinates from T.S. to S.C. and S.T. to C.S.

$\theta$ = spiral angle at any point on spiral.

$\theta_s$ = spiral angle at S.C. or C.S.

$L$ = length of spiral, T.S. to any point on spiral.

$L_s$ = length of spiral, T.S. to S.C. or S.T. to C.S.

$D_c$ = degree of circular curve (arc definition).

$D$ = degree of curve at any point on spiral.

$x, y$ = coordinates from T.S. or S.T. to any point on spiral.

$\phi_c$ = deflection from tangent at T.S. to S.C.

$\phi$ = deflection from tangent at T.S., S.T. or any point on spiral to any other point on spiral.

L.T., S.T. = long tangent, short tangent.

L.C. = long chord of spiral transition.

$\Delta$ = intersection and central angle of entire curve.

$\Delta_c$ = intersection and central angle of circular curve.

$L_c$ = length of circular curve, S.C. to C.S.

*Note.* The degree of curvature varies directly as the length, from zero curvature at T.S. to the maximum of *Dc* at the S.C. The spiral departs from the circular curve at the same rate as from the tangent.

## Spiral Layout (See pp. 221, 222, 223 also.)

Method I: Deflections to even stations by formula $\phi = \theta/3 = 1/3\theta_s(L/L_s)^2$. Correct $\phi$ for $c$ when $\theta > 20°$.

**TABLE 10. $C$ IN FORMULA, $\phi = \theta/3 - C$**

(For curves with $\theta$ over 20°)

| $\theta$ in degrees | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|
| $c$ in minutes | 0.4 | 0.8 | 1.4 | 2.2 | 3.4 | 4.8 | 5.6 |

Method II: Offsets from tangent. Establish by measuring $x$ distances from T.S. and $y$ distances from tangent. Compute $\theta$ for each point and then compute $x$ and $y$ coordinates from Table 12, p. 224, or use ¼ point formulas above.

Method III: Deflection angle from T.S. or S.T. to any point on spiral with coordinates $x$ and $y$ is the angle whose tangent $= y/x$.

Method IV: Deflection angles from T.S. to points of 10 equal divisions (10 chord spiral) are: $0.01\phi_c$; $0.04\phi_c$; $0.16\phi_c$; $0.25\phi_c$; $0.36\phi_c$; $0.49\phi_c$; $0.64\phi_c$; $0.81\phi_c$ and $\phi_c$.

**TABLE 11. MINIMUM TRANSITION LENGTHS**

| $D_c$ | 30 M.P.H. | 40 M.P.H. | 50 M.P.H. | 60 M.P.H. | 70 M.P.H. | $D_c$ |
|---|---|---|---|---|---|---|
| | $L_s$ | $L_s$ | $L_s$ | $L_s$ | $L_s$ | |
| 1° 30′ | 150′ | 150′ | 150′ | 150′ | 150′ | 1° 30′ |
| 2° | 150′ | 150′ | 150′ | 150′ | 200′ | 2° |
| 2° 30′ | 150′ | 150′ | 150′ | 150′ | 250′ | 2° 30′ |
| 3° | 150′ | 150′ | 150′ | 150′ | 300′ | 3° |
| 3° 30′ | 150′ | 150′ | 150′ | 200′ | 350′ | 3° 30′ |
| 4° | 150′ | 150′ | 150′ | 250′ | 400′ | 4° |
| 5° | 150′ | 150′ | 150′ | 300′ | | |
| 6° | 150′ | 150′ | 200′ | 350′ | | |
| 7° | 150′ | 150′ | 250′ | | | |
| 8°–9° | 150′ | 150′ | 300′ | | | |
| 10°–12° | 150′ | 200′ | | | | |
| 13°–14° | 150′ | 250′ | | | | |
| 15°–23° | 150′ | | | | | |
| 24° | 200′ | | | | | |

Based on

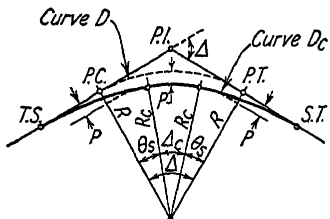
$$L_s = \frac{1.6V^3}{R_c}$$

Where: $V$ = 0.75 design speed in M.P.H.

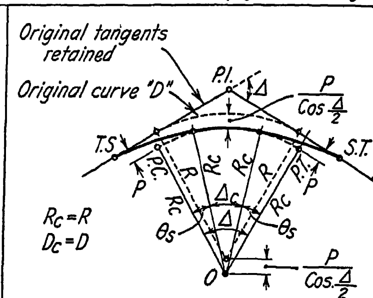
Min. $L_s$ = 150 ft.

## INSERTION OF SPIRALS INTO EXISTING ALIGNMENT OF CIRCULAR CURVES

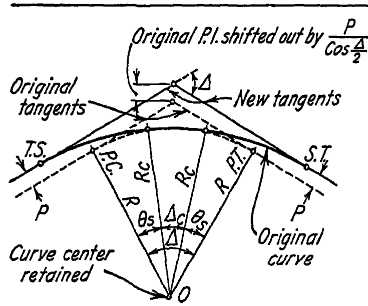
$L_s$ = Length of spiral select from table 11, page 219
$\theta_s$ = Spiral angle = $\frac{L_s D_c}{200}$, where $D_c$ = Degree of curvature (arc definition).
$P$ = Offset of curve at P.C. to permit spiral introduction from table, page 224, knowing $\theta_s$.



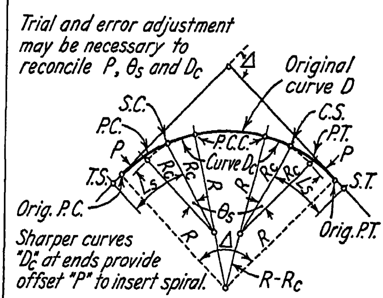

CASE I - *Radius of original circular curve reduced by value of "P" to provide space to insert spiral transition.*
*1st trial : Assume $D_c = D$, find trial "P" as above.*
*2nd trial: Compute $D_c = \frac{5727.58}{R_c}$, find correct "P."*




CASE II - *Radius of original curve retained and curve center "O" shifted inward.*
*Note: Degree of curve retained.*

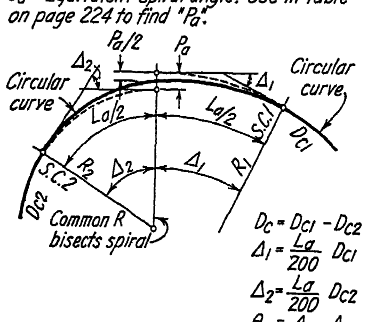



CASE III - *Original circular curve location retained and tangents shifted outward to insert spiral.*

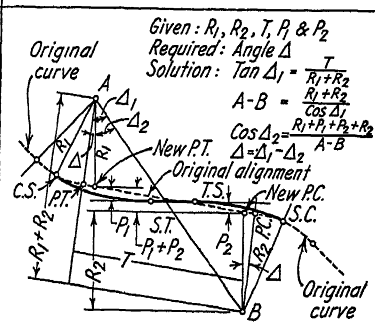



CASE IV - *Original alignment retained as closely as possible by compounding circular curve at both ends.*

$\theta_a$ = Equivalent spiral angle. Use in table on page 224 to find "$P_a$".




CASE V - *To insert a spiral in a compound curve.*




CASE VI - *To insert spirals between simple reverse curves separated by a tangent.*

## PROPERTIES AND EXAMPLES *

### PROPERTIES OF SPIRAL

1. Offsets, $y$, vary as the cube of $L$, or length of spiral. $\therefore$ $y$ at any point $= (L/L_s)^3 y_c$. See Fig. 11.

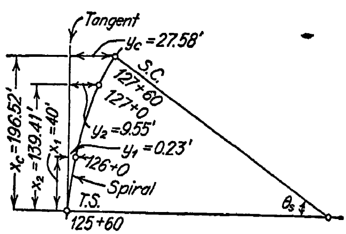
2. Spiral angle $\theta$ varies as $L^2$. $\therefore$ $\theta$ at any point on spiral $= (L/L_s)^2\theta_s$.

3. Deflection angle $\phi$ varies as $L^2$. $\therefore$ $\phi = (L/L_s)^2\phi_c$. $\phi_c = \frac{1}{3}\theta_s - c$, $c$ being a constant; see Table 10, p. 219. (May be neglected for ordinary problems.)

4. $D$, or degree of curve of spiral at any point, varies directly as $L$. $\therefore$ $D = L/L_s\, D_c$.

5. Spiral bisects $P$ very nearly and $k$ approximately $= \frac{1}{2}L_s$. $\therefore$ Offset from circular curve or tangent to midpoint of spiral is $\frac{1}{2}P$ very nearly.

6. Spiral departs from the circular curve between S.C. and P.C. at the same rate as from the tangent. $\therefore$ Radial offsets from circular curve between S.C. and P.C. to the spiral are the same as perpendicular offsets from the tangent between T.S. and P.C.

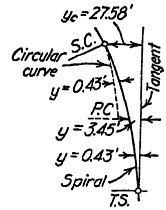



*Given.* Spiral $L_s = 200'$; $\theta_s = 24°$; T.S. at Sta. 125 + 60.
*Required.* Offsets to even stations.
*Solution.* Compute $\theta$ and read $x$ and $y$ for $L_s = 1$ from table on 224.

| Sta. | $L$ | $\theta$ | $x, L_s = 1$ | $y, L_s = 1$ | $x$ | $y$ |
|---|---|---|---|---|---|---|
| 126 + 0 | 40 | 0° 58′ | 0.99997 | 0.00559 | 40.0 | 0.22 |
| 127 + 0 | 140 | 11° 46′ | 0.99578 | 0.06821 | 139.41 | 9.55 |
| 127 + 60 | 200 | 24° 0′ | 0.98260 | 0.13789 | 196.52 | 28.58 |

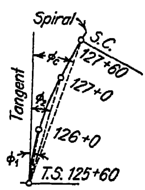
FIG. 11. Offsets to even stations.

* *Reference Transition Curves for Highways by Joseph Barnett, P.R.A.*




*Given.* Spiral, $L_s = 200'$; $\theta_s = 24°$.
*Required.* Offsets to ¼ points.
*Solution.* From Fig. 11, $y_c = 27.58'$. By formula, $y$ at any point $= (L/L_s)^3 y_c$
At ¼ points, $y = 27.58 \times 1/64 = 0.43'$.
At ½ points, $y = 27.58 \times 1/8 = 3.45'$.

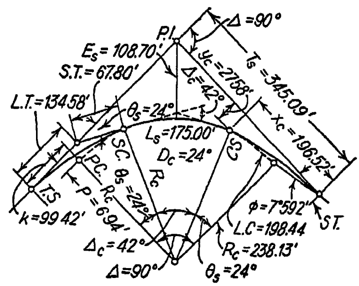
FIG. 12. Offsets to ¼ points.




*Given.* Spiral with $L_s = 200'$ and $\theta_s = 24°$.
*Required.* Deflection angles $\phi$, to Sta. 126 + 0; $\phi_2$ to Sta. 127 + 0; $\phi_c$ to Sta. 127 + 60.
*Solution.* By formulas, $\phi_c = \theta_s/3 - c$ and $\phi = \frac{1}{3}(L/L_s)^2 \theta_s - c$.
Sta. 127 + 60: $\phi_c = 24/3 - 0.8 = 7.9866° = 7° 69.2'$
Sta. 126 + 00: $\phi_1 = (L/L_s)^2\phi_c = (40/200)^2 \times 7.9866$
$= 0.3195° = 0° 19'$
Sta. 127 + 00: $\phi_2 = (L/L_s)^2\phi_c = (140/200)^2 \times 7.9866$
$= 3.9134° = 3° 55'$

*Layout.* With transit at T.S., foresight along tangent with vernier at 0° Turn $\phi_1$ and measure 40 ft. to Sta. 126 + 0. Turn $\phi_2$ and measure 100 ft. from Sta. 126 + 0 to Sta. 127 + 0. Turn $\phi_c$ and measure 60′ from Sta. 127 + 0 to S.C.

FIG. 13. Deflections to even stations.




*Given.* $\Delta = 90°$; $D_c = 24°$; $L_s = 200'$. Formulas from p. 217. Functions of spiral for $L_s = 1$ from p. 224.

For layout of circular curve, see pp. 202, 203, 204.

## Layout of Control Points *

Establish T.S. by measuring $k$ from P.O.T. normal to P.C. or by $T_s$ from P.I. Establish S.C. by L.T., $\theta_s$, and S.T. or by $x_c$ and $y_c$ from T.S., or by $\phi_c$ and L.C. from T.S.

*Note.* Figures 11–13 give all dimensions usually necessary to plot or locate the spiral. The following example is a curve fully worked out.

| Required | Formula | Solution |
|---|---|---|
| $\theta_s$ | $L_sD_c \div 200$ | $\theta_s = 24°$ |
| $\Delta_c$ | $\Delta - (L_sD_c \div 100)$ | $\Delta_c = 42°$ |
| $L_c$ | $100\Delta_c \div D_c$ | $L_c = 175.00$ |
| $\phi_c$ | $\frac{1}{3}\theta_s - c$ | $\phi_c = 7° \, 59.2'$ |
| $y_c$ | $(y \text{ for } L_s = 1)\cdot L_s$ | $y_c = 27.58'$ |
| $x_c$ | $(x \text{ for } L_s = 1)\cdot L_s$ | $x_c = 196.52'$ |
| $P$ | $y_c - R_c(1 - \cos\theta_s)$ | $P = 6.94'$ |
| $k$ | $x_c - R_c \sin\theta_s$ | $k = 99.42'$ |
| $E_s$ | $(R_c + P) \text{ exsec } \Delta/2 + P$ | $E_s = 108.70'$ |
| $T_s$ | $(R_c + P) \tan \Delta/2 + k$ | $T_s = 345.09'$ |
| L.T. | (L.T. for $L_s = 1)L_s$; $\theta = 24°$ | L.T. = 134.58' |
| S.T. | (S.T. for $L_s = 1)L_s$; $\theta = 24°$ | S.T. = 67.80' |
| L.C. | (L.C. for $L_s = 1)L_s$; $\theta = 24°$ | L.C. = 198.44 |

Fig. 14. Computations for spiral transitions to circular curves.

* *Adapted from O'Rourke, General Engineering Handbook, McGraw-Hill.*

## TABLE 12. FUNCTIONS OF TRANSITION FOR $L_s = 1$ *

Enter table with value of $\theta$ or $\theta_s$, and multiply function by $L$ or $L_s$. See pp. 218–223 for use of table.

| $\theta$ | $p$ | $k$ | $x$ | $y$ | L.T. | S.T. | L.C. | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| 0° | .00000 | .50000 | 1.00000 | .00000 | .66667 | .33333 | 1.00000 | 0° |
| 1° | .00146 | .49999 | .99997 | .00582 | .66668 | .33334 | .99999 | 1° |
| 2° | .00291 | .49998 | .99988 | .01163 | .66671 | .33337 | .99995 | 2° |
| 3° | .00435 | .49995 | .99973 | .01745 | .66676 | .33342 | .99988 | 3° |
| 4° | .00581 | .49992 | .99951 | .02326 | .66684 | .33349 | .99978 | 4° |
| 5° | .00727 | .49987 | .99924 | .02907 | .66693 | .33358 | .99966 | 5° |
| 6° | .00872 | .49982 | .99890 | .03488 | .66705 | .33368 | .99951 | 6° |
| 7° | .01018 | .49975 | .99851 | .04068 | .66719 | .33381 | .99934 | 7° |
| 8° | .01163 | .49967 | .99805 | .04648 | .66735 | .33395 | .99913 | 8° |
| 9° | .01308 | .49959 | .99754 | .05227 | .66753 | .33412 | .99890 | 9° |
| 10° | .01453 | .49949 | .99696 | .05805 | .66773 | .33430 | .99865 | 10° |
| 11° | .01598 | .49939 | .99632 | .06383 | .66796 | .33451 | .99836 | 11° |
| 12° | .01743 | .49927 | .99562 | .06959 | .66821 | .33473 | .99805 | 12° |
| 13° | .01887 | .49914 | .99486 | .07535 | .66847 | .33498 | .99771 | 13° |
| 14° | .02032 | .49901 | .99405 | .08110 | .66877 | .33524 | .99735 | 14° |
| 15° | .02176 | .49886 | .99317 | .08684 | .66908 | .33553 | .99696 | 15° |
| 16° | .02320 | .49870 | .99223 | .09257 | .66941 | .33583 | .99654 | 16° |
| 17° | .02465 | .49854 | .99123 | .09828 | .66977 | .33615 | .99609 | 17° |
| 18° | .02608 | .49836 | .99018 | .10398 | .67015 | .33650 | .99562 | 18° |
| 19° | .02752 | .49817 | .98906 | .10967 | .67055 | .33687 | .99512 | 19° |
| 20° | .02896 | .49798 | .98788 | .11535 | .67097 | .33725 | .99460 | 20° |
| 21° | .03040 | .49777 | .98665 | .12101 | .67142 | .33766 | .99404 | 21° |
| 22° | .03183 | .49755 | .98536 | .12665 | .67189 | .33809 | .99346 | 22° |
| 23° | .03326 | .49733 | .98401 | .13228 | .67238 | .33854 | .99286 | 23° |
| 24° | .03469 | .49709 | .98260 | .13789 | .67290 | .33901 | .99222 | 24° |
| 25° | .03611 | .49684 | .98113 | .14348 | .67344 | .33950 | .99157 | 25° |
| 26° | .03753 | .49658 | .97960 | .14905 | .67400 | .34001 | .99088 | 26° |
| 27° | .03896 | .49632 | .97802 | .15461 | .67459 | .34055 | .99017 | 27° |
| 28° | .04037 | .49605 | .97638 | .16014 | .67520 | .34111 | .98943 | 28° |
| 29° | .04179 | .49576 | .97469 | .16565 | .67584 | .34169 | .98866 | 29° |
| 30° | .04321 | .49546 | .97293 | .17114 | .67650 | .34229 | .98787 | 30° |
| 31° | .04462 | .49516 | .97112 | .17661 | .67719 | .34292 | .98705 | 31° |
| 32° | .04602 | .49484 | .96926 | .18206 | .67790 | .34356 | .98621 | 32° |
| 33° | .04743 | .49452 | .96733 | .18748 | .67863 | .34424 | .98534 | 33° |
| 34° | .04883 | .49419 | .96536 | .19288 | .67939 | .34493 | .98444 | 34° |
| 35° | .05023 | .49385 | .96332 | .19826 | .68018 | .34565 | .98351 | 35° |
| 36° | .05163 | .49349 | .96124 | .20361 | .68100 | .34640 | .98257 | 36° |
| 37° | .05301 | .49313 | .95910 | .20893 | .68184 | .34717 | .98159 | 37° |
| 38° | .05441 | .49276 | .95690 | .21423 | .68271 | .34796 | .98059 | 38° |
| 39° | .05579 | .49238 | .95466 | .21949 | .68360 | .34878 | .97956 | 39° |
| 40° | .05718 | .49199 | .95235 | .22473 | .68452 | .34962 | .97851 | 40° |
| 41° | .05855 | .49159 | .95000 | .22994 | .68547 | .35049 | .97743 | 41° |
| 42° | .05993 | .49118 | .94759 | .23513 | .68645 | .35139 | .97632 | 42° |
| 43° | .06130 | .49075 | .94513 | .24028 | .68746 | .35232 | .97519 | 43° |
| 44° | .06267 | .49032 | .94262 | .24540 | .68850 | .35327 | .97404 | 44° |
| 45° | .06403 | .48990 | .94005 | .25049 | .68957 | .35424 | .97285 | 45° |
| 46° | .06538 | .48945 | .93744 | .25555 | .69066 | .35525 | .97165 | 46° |
| 47° | .06674 | .48900 | .93477 | .26057 | .69179 | .35629 | .97041 | 47° |
| 48° | .06809 | .48852 | .93206 | .26556 | .69295 | .35735 | .96916 | 48° |
| 49° | .06944 | .48805 | .92930 | .27052 | .69414 | .35844 | .96787 | 49° |
| 50° | .07078 | .48757 | .92649 | .27544 | .69536 | .35957 | .96656 | 50° |

* *Adapted from Transi.ion Curves for Highways by Joseph Barnett, P.R.A.*

## TABLE 13. FUNCTIONS OF CURVES TRANSITIONAL THROUGHOUT

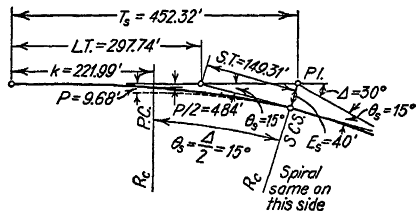
### TANGENTS AND EXTERNALS FOR $L_s = 1$*

| Δ° | $T_s$ | $E_s$ | Δ° | $T_s$ | $E_s$ | Δ° | $T_s$ | $E_s$ |
|---|---|---|---|---|---|---|---|---|
| 6° | 1.00064 | 0.01747 | 38° | 1.02682 | 0.11599 | 70° | 1.10214 | 0.24203 |
| 7 | 1.00087 | 0.02040 | 39 | 1.02832 | 0.11936 | 71 | 1.10561 | 0.24681 |
| 8 | 1.00114 | 0.02332 | 40 | 1.02987 | 0.12275 | 72 | 1.10917 | 0.25167 |
| 9 | 1.00144 | 0.02625 | 41 | 1.03146 | 0.12617 | 73 | 1.11281 | 0.25660 |
| 10 | 1.00178 | 0.02918 | 42 | 1.03310 | 0.12962 | 74 | 1.11654 | 0.26161 |
| 11 | 1.00216 | 0.03213 | 43 | 1.03479 | 0.13309 | 75 | 1.12036 | 0.26669 |
| 12 | 1.00257 | 0.03507 | 44 | 1.03653 | 0.13660 | 76 | 1.12427 | 0.27186 |
| 13 | 1.00302 | 0.03802 | 45 | 1.03831 | 0.14012 | 77 | 1.12828 | 0.27710 |
| 14 | 1.00350 | 0.04098 | 46 | 1.04015 | 0.14370 | 78 | 1.13240 | 0.28244 |
| 15 | 1.00402 | 0.04396 | 47 | 1.04204 | 0.14730 | 79 | 1.13661 | 0.28786 |
| 16 | 1.00458 | 0.04693 | 48 | 1.04399 | 0.15094 | 80 | 1.14092 | 0.29337 |
| 17 | 1.00518 | 0.04992 | 49 | 1.04598 | 0.15460 | 81 | 1.14535 | 0.29898 |
| 18 | 1.00581 | 0.05292 | 50 | 1.04804 | 0.15831 | 82 | 1.14988 | 0.30468 |
| 19 | 1.00648 | 0.05593 | 51 | 1.05014 | 0.16206 | 83 | 1.15453 | 0.31048 |
| 20 | 1.00719 | 0.05895 | 52 | 1.05230 | 0.16584 | 84 | 1.15930 | 0.31639 |
| 21 | 1.00794 | 0.06198 | 53 | 1.05452 | 0.16966 | 85 | 1.16418 | 0.32241 |
| 22 | 1.00873 | 0.06502 | 54 | 1.05680 | 0.17352 | 86 | 1.16919 | 0.32854 |
| 23 | 1.00955 | 0.06808 | 55 | 1.05913 | 0.17742 | 87 | 1.17433 | 0.33478 |
| 24 | 1.01042 | 0.07115 | 56 | 1.06153 | 0.18137 | 88 | 1.17960 | 0.34115 |
| 25 | 1.01132 | 0.07424 | 57 | 1.06399 | 0.18536 | 89 | 1.18500 | 0.34763 |
| 26 | 1.01226 | 0.07734 | 58 | 1.06651 | 0.18940 | 90 | 1.19054 | 0.35425 |
| 27 | 1.01324 | 0.08045 | 59 | 1.06909 | 0.19348 | 91 | 1.19623 | 0.36099 |
| 28 | 1.01427 | 0.08358 | 60 | 1.07174 | 0.19762 | 92 | 1.20207 | 0.36788 |
| 29 | 1.01533 | 0.08674 | 61 | 1.07446 | 0.20181 | 93 | 1.20806 | 0.37490 |
| 30 | 1.01644 | 0.08990 | 62 | 1.07724 | 0.20604 | 94 | 1.21421 | 0.38207 |
| 31 | 1.01758 | 0.09309 | 63 | 1.08010 | 0.21034 | 95 | 1.22052 | 0.38940 |
| 32 | 1.01877 | 0.09630 | 64 | 1.08302 | 0.21468 | 96 | 1.22700 | 0.39688 |
| 33 | 1.02000 | 0.09952 | 65 | 1.08602 | 0.21908 | 97 | 1.23366 | 0.40453 |
| 34 | 1.02128 | 0.10277 | 66 | 1.08909 | 0.22355 | 98 | 1.24050 | 0.41234 |
| 35 | 1.02260 | 0.10604 | 67 | 1.09223 | 0.22807 | 99 | 1.24753 | 0.42034 |
| 36 | 1.02396 | 0.10933 | 68 | 1.09546 | 0.23266 | 100 | 1.25475 | 0.42852 |
| 37 | 1.02537 | 0.11265 | 69 | 1.09876 | 0.23731 | | | |

* *Adapted from Transition Curves for Highways by Joseph Barnett, P.R.A.*

*Case VII.* Given $\Delta$ and an external or tangent distance; to determine a curve transitional throughout.

Enter Table 13 at known $\Delta$ and read $T_s$ and $E_s$ values. Then $L_s = E_s/E_s$ value and $T_s = L_s \cdot$ tangent value, or $L_s = T_s/T_s$ value and $E_s = L_s \cdot$ external value.




EXAMPLE. *Given.* $\Delta = 30°$ and $E_s = 40'$.

*Required.* $L_s$, $T_s$, $\theta_s$, L.T., S.T., $D_c$, $P$, and $k$.

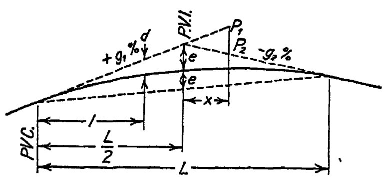
*Solution.* $L_s = 40 \div 0.08990 = 444.9$, say $445'$. $T_s = 1.01644 \times 445 = 452.32'$. $\theta_s = \dfrac{\Delta}{2} = 15°$. $D_c = \dfrac{200\theta_s}{L_s} = 6.47'$. L.T. $= 0.66908 \times 445 = 297.74'$. S.T. $= 0.33553 \times 445 = 149.31'$. $p = 0.02176 \times 445 = 9.68'$. $k = 498.86 \times 445 = 221.99'$.

FIG. 15. Spiral layout by offsets or deflections (same as for spiral transitions to a circular curve).

## VERTICAL CURVES (Parabolic)

FORMULAS

$A$ = algebraic difference of grades = $+g_1\% - (-g_2\%)$.
$e = AL/8$.
$d = l^2A/2L$; $d = 4e\,(l/L)^2$.




VERTICAL SUMMIT CURVE

Length of vertical summit curves should provide required sight distance. See Vol. I, p. 3-60.

*Note.* All horizontal distances shown on this page—$L$, $l$, $l_1$, $l_2$, $x$, $x_1$, $x_2$—are expressed in 100 ft. stations.

Where $L$, length of vertical curve, is not determined by sight distance criteria, the minimum value for comfort is

$$L = \frac{AV^2}{10{,}000}\,*$$

EXAMPLE. *Given.* $g_1\% = +3.00\%$; $g_2\% = -2.00\%$; $L = 3.00$; $l = 0.50$.
*Required.* $A$, $e$, and $d$.
*Solution.*

$$A = 3.00 - (-2.00) = 5.00$$

$$e = \frac{5.00 \times 3.00}{8} = 1.875'$$

$$d = \frac{0.50^2 \times 5.00}{2 \times 3.00} = 0.208'$$

Also,

$$d = 4(1.875)\left(\frac{0.50}{3.00}\right)^2 = 0.208'.$$

*To find Sta. of P.V.I. when elevations of $P_1$ and $P_2$ are known.*

FORMULA

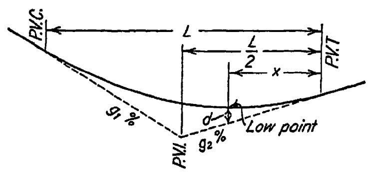
$$x = \frac{\text{elev. } P_1 - \text{elev. } P_2}{A}$$

EXAMPLE. *Given.* Elev. $P_1 = 154.50$; elev. $P_2 = 150.00$; $A = 5.00$.
*Required.* $x$ = distance in 100′ stations from known point to P.V.I.

* *From O'Rourke, General Engineering Handbook, McGraw-Hill.*

*Solution.*

$$x = \frac{154.50 - 150.00}{5.00} = 0.90(100' \text{ stations})$$




*To find low point on sag curve.*

VERTICAL SAG CURVE

Length of vertical sag curve should provide headlight illumination for a safe stopping distance. See Vol. I, p. 3-62.

FORMULAS

$x = g$(lesser gradient) $L/A$.
$d$(at low point) $= x^2A/2L$.

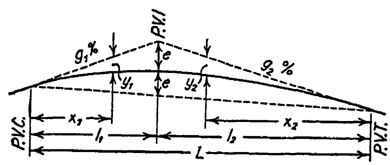
EXAMPLE. *Given.* $g_1\% = -3.00\%$; $g_2 = +2.00\%$; $L = 3.00$; $A = 5.00$.
*Required.* $x$ and $d$.
*Solution.*

$$x = 2.00 \times \frac{3.00}{5.00} = 1.20'$$

$$d = \frac{1.20^2 \times 5.00}{2 \times 3.00} = 1.20'$$

*Note.* High point on summit curve can be found by same method.

FIG. 16. Symmetrical vertical curves.




FORMULAS

$$e = \frac{l_1 l_2}{2(l_1 + l_2)}(g_1 - g_2);\ y_1 = e\left(\frac{x_1}{l_1}\right)^2;\ y_2 = e\left(\frac{x_2}{l_2}\right)^2$$

EXAMPLE. *Given.* $g_1 = 3.00\%$; $g_2 = 2.00\%$; $L = 4.00$; $l_1 = 1.50$; $l_2 = 2.50$; $x_1 = 0.50$; $x_2 = 1.00$.

*Required.* $e$, $y_1$, and $y_2$.

*Solution.*

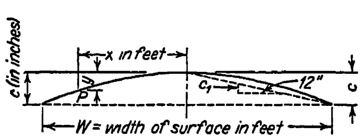
$$e = \frac{1.50 \times 2.50}{2(1.50 + 2.50)}(3.00 + 2.00) = 2.35'$$

$$y_1 = 2.35\left(\frac{0.50}{1.50}\right)^2 = 0.26'$$

$$y_2 = 2.35\left(\frac{1.00}{2.50}\right)^2 = 0.38'$$

FIG. 17. Unsymmetrical vertical curves used to fit unusual conditions.

## PARABOLIC CROWN ORDINATES




FORMULAS

SYMMETRICAL CROWN

Used for roads and for streets where gutters are same elevation.

$$c = c_1\left(\frac{W}{2}\right);\ y = 4c\left(\frac{x}{W}\right)^2.$$

EXAMPLE. *Given.* $c_1 = \frac{1}{8}''$; $W = 22'$; and $x = 6'$.

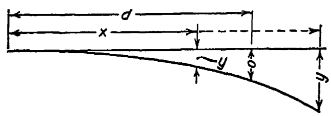
*Required.* $c$; $y$ (at any point $P$).

*Solution.*

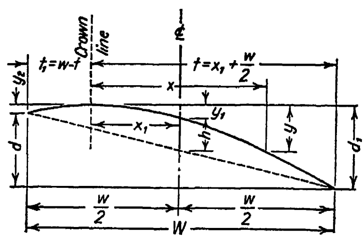
$$c = \frac{1}{8} \times \frac{22}{2} = 1.375'' = 1\frac{3}{8}''$$

$$y = 4 \times 1.375\left(\frac{6}{22}\right)^2 = 0.409'' = \frac{13}{32}''$$

## Ordinates—Any Parabolic Curve




## Unsymmetrical Crown.




Used for city streets where conditions necessitate different gutter elevations. If slope per foot is over ½ in., a stepped curb or retaining wall should be used on uphill side of street.

Also used for off-center crowns on three-lane roads to provide symmetrical crown for future four lanes.

Also used for transition onto superelevated curves.

Offsets from tangent to curve vary directly as the squares of the tangent distances.

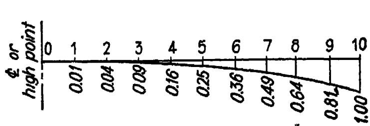
Formula

$$d^2 : x^2 = o : y. \quad \therefore\ y = \frac{ox^2}{d^2}.$$

Example. *Given.* $d = 10'$; $o = 6''$; and $x = 5'$.
*Required.* $y$.
*Solution.*

$$y = \frac{6 \times 5^2}{10^2} = 1.50'' = 1\tfrac{1}{2}''$$

## Alternative Method




Divide the distance from center line or high point to edge of pavement into 10 equal spaces. Multiply figures in chart by total crown to get ordinates from crown elevation to pavement surface for points shown.

EXAMPLE. *Given.* Total crown = 6″.
*Required.* Ordinates at fifth and eighth points.
*Solution.*
Ordinate at fifth point = 0.25 × 6 = 1.50″ = 1½″.
Ordinate at eighth point = 0.64 × 6 = 3.84″ = 3$^{13}/_{16}$″.

FORMULAS

$$x_1 = \frac{dw}{8h}\,;\; y_1 = \frac{d^2}{16h}\,;\; d_1 = \frac{d}{2} + h + y_1;\; y = \frac{d_1 x^2}{t^2}$$

$$y_2 = d_1 - d;\; t = x_1 + \frac{w}{2}\,;\; t_1 = W - t$$

EXAMPLE. *Given.* $h = 0.5'$; $w = 40'$; $d = 0.5'$; $x = 10'$.
*Required.* $x_1$; $y_1$; $d_1$; $y_2$; $y$; $t$ and $t_1$.
*Solution.*

$$x_1 = \frac{0.5 \times 40}{8 \times 0.5} = 5.0'$$

$$y_1 = \frac{0.5^2}{16 \times 0.5} = 0.0312' = 0.375'' = 3/8''$$

$$d_1 = \frac{0.5}{2} + 0.5 + 0.0312 = 0.7812' = 9.375'' = 9\,3/8''$$

$$y_2 = 0.7812 - 0.5 = 0.2812' = 3.375'' = 3\,3/8''$$

$$t = 5.0 + \frac{40}{2} = 25.0'$$

$$y = \frac{0.7812 \times 10^2}{25^2} = 0.125'' = 1/2''$$

$$t_1 = 40 - 25 = 15'$$

# TABLE 14. PARABOLIC CROWN ORDINATES

## ORDINATES FROM GRADE TANGENT TO SURFACE FOR EACH FOOT OF WIDTH SURFACE WIDTH OF STREET OR ROAD

**20′**

| ½″:1′ Crown | | |
|---|---|---|
| 1 | 1/16″ | .004′ |
| 2 | 3/16″ | .017′ |
| 3 | 7/16″ | .037′ |
| 4 | 13/16″ | .067′ |
| 5 | 1¼″ | .104′ |
| 6 | 1 13/16″ | .150′ |
| 7 | 2 7/16″ | .204′ |
| 8 | 3 3/16″ | .267′ |
| 9 | 4 1/16″ | .337′ |
| 10 | 5″ | .417′ |

| ⅜″:1′ Crown | | |
|---|---|---|
| 1 | 1/16″ | .003′ |
| 2 | ⅛″ | .012′ |
| 3 | 5/16″ | .028′ |
| 4 | ⅝″ | .050′ |
| 5 | 15/16″ | .078′ |
| 6 | 1⅜″ | .112′ |
| 7 | 1 13/16″ | .153′ |
| 8 | 2⅜″ | .200′ |
| 9 | 3 1/16″ | .253′ |
| 10 | 3¾″ | .312′ |

| ¼″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .002′ |
| 2 | ⅛″ | .008′ |
| 3 | ¼″ | .019′ |
| 4 | ⅜″ | .033′ |
| 5 | ⅝″ | .052′ |
| 6 | ⅞″ | .075′ |
| 7 | 1¼″ | .102′ |
| 8 | 1⅝″ | .133′ |
| 9 | 2¼″ | .190′ |
| 10 | 2½″ | .208′ |

**22′**

| ⅜″:1′ Crown | | |
|---|---|---|
| 1 | 1/16″ | .003′ |
| 2 | ⅛″ | .011′ |
| 3 | 5/16″ | .026′ |
| 4 | 9/16″ | .045′ |
| 5 | ⅞″ | .071′ |
| 6 | 1¼″ | .102′ |
| 7 | 1 11/16″ | .139′ |
| 8 | 2 3/16″ | .182′ |
| 9 | 2¾″ | .230′ |
| 10 | 3 7/16″ | .284′ |
| 11 | 4⅛″ | .344′ |

| ¼″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .002′ |
| 2 | ⅛″ | .008′ |
| 3 | 3/16″ | .017′ |
| 4 | ⅜″ | .030′ |
| 5 | 9/16″ | .047′ |
| 6 | 13/16″ | .068′ |
| 7 | 1⅛″ | .093′ |
| 8 | 1 7/16″ | .121′ |
| 9 | 1 13/16″ | .153′ |
| 10 | 2¼″ | .189′ |
| 11 | 2¾″ | .229′ |

| ⅛″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .001′ |
| 2 | 1/16″ | .004′ |
| 3 | ⅛″ | .009′ |
| 4 | 3/16″ | .015′ |
| 5 | 5/16″ | .024′ |
| 6 | 7/16″ | .034′ |
| 7 | 9/16″ | .046′ |
| 8 | ¾″ | .061′ |
| 9 | 15/16″ | .077′ |
| 10 | 1⅛″ | .095′ |
| 11 | 1⅜″ | .115′ |

**34′**

| ¼″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .003′ |
| 2 | 1/16″ | .005′ |
| 3 | ⅛″ | .011′ |
| 4 | ¼″ | .020′ |
| 5 | ⅜″ | .031′ |
| 6 | ½″ | .044′ |
| 7 | ¾″ | .060′ |
| 8 | 15/16″ | .078′ |
| 9 | 1 3/16″ | .099′ |
| 10 | 1½″ | .123′ |
| 11 | 1¾″ | .148′ |
| 12 | 2⅛″ | .176′ |
| 13 | 2½″ | .207′ |
| 14 | 2⅞″ | .240′ |
| 15 | 3 5/16″ | .276′ |
| 16 | 3¾″ | .314′ |
| 17 | 4¼″ | .354′ |

| ⅛″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .001′ |
| 2 | 0″ | .002′ |
| 3 | 1/16″ | .006′ |
| 4 | ⅛″ | .010′ |
| 5 | 3/16″ | .015′ |
| 6 | ¼″ | .022′ |
| 7 | ⅜″ | .030′ |
| 8 | 7/16″ | .039′ |
| 9 | ⅝″ | .050′ |
| 10 | ¾″ | .061′ |
| 11 | ⅞″ | .074′ |
| 12 | 1 1/16″ | .088′ |
| 13 | 1¼″ | .104′ |
| 14 | 1 7/16″ | .120′ |
| 15 | 1⅝″ | .138′ |
| 16 | 1⅞″ | .157′ |
| 17 | 2⅛″ | .177′ |

**40′**

| ¼″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .000′ |
| 2 | 1/16″ | .004′ |
| 3 | ⅛″ | .009′ |
| 4 | 3/16″ | .017′ |
| 5 | 5/16″ | .026′ |
| 6 | 7/16″ | .038′ |
| 7 | ⅝″ | .051′ |
| 8 | 13/16″ | .067′ |
| 9 | 1″ | .084′ |
| 10 | 1¼″ | .104′ |
| 11 | 1½″ | .126′ |
| 12 | 1 13/16″ | .150′ |
| 13 | 2⅛″ | .176′ |
| 14 | 2 7/16″ | .204′ |
| 15 | 2 13/16″ | .234′ |
| 16 | 3 3/16″ | .267′ |
| 17 | 3⅝″ | .301′ |
| 18 | 4 1/16″ | .338′ |
| 19 | 4½″ | .376′ |
| 20 | 5″ | .417′ |

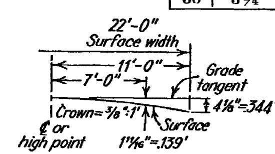
| ⅛″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .001′ |
| 2 | 0″ | .002′ |
| 3 | 1/16″ | .005′ |
| 4 | ⅛″ | .008′ |
| 5 | 3/16″ | .013′ |
| 6 | ¼″ | .019′ |
| 7 | 5/16″ | .026′ |
| 8 | ⅜″ | .033′ |
| 9 | ½″ | .042′ |
| 10 | ⅝″ | .052′ |
| 11 | ¾″ | .063′ |
| 12 | ⅞″ | .075′ |
| 13 | 1 1/16″ | .088′ |
| 14 | 1¼″ | .102′ |
| 15 | 1⅜″ | .117′ |
| 16 | 1⅝″ | .133′ |
| 17 | 1 13/16″ | .151′ |
| 18 | 2″ | .169′ |
| 19 | 2¼″ | .188′ |
| 20 | 2½″ | .208′ |

**44′**

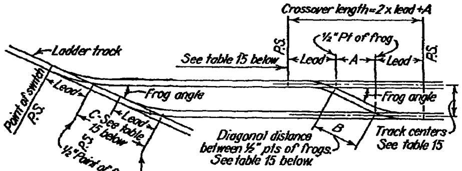
| ⅛″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .000′ |
| 2 | 0″ | .002′ |
| 3 | 1/16″ | .004′ |
| 4 | ⅛″ | .008′ |
| 5 | ⅛″ | .012′ |
| 6 | 3/16″ | .017′ |
| 7 | ¼″ | .023′ |
| 8 | ⅜″ | .030′ |
| 9 | 7/16″ | .038′ |
| 10 | 9/16″ | .047′ |
| 11 | 11/16″ | .057′ |
| 12 | 13/16″ | .068′ |
| 13 | 15/16″ | .080′ |
| 14 | 1⅛″ | .093′ |
| 15 | 1 5/16″ | .107′ |
| 16 | 1 7/16″ | .121′ |
| 17 | 1⅝″ | .137′ |
| 18 | 1 13/16″ | .153′ |
| 19 | 2 1/16″ | .171′ |
| 20 | 2¼″ | .189′ |
| 21 | 2½″ | .209′ |
| 22 | 2¾″ | .229′ |

**60′**

| ⅛″:1′ Crown | | |
|---|---|---|
| 1 | 0″ | .000′ |
| 2 | 0″ | .001′ |
| 3 | 1/16″ | .003′ |
| 4 | 1/16″ | .005′ |
| 5 | ⅛″ | .008′ |
| 6 | ⅛″ | .012′ |
| 7 | 3/16″ | .017′ |
| 8 | ¼″ | .022′ |
| 9 | 5/16″ | .028′ |
| 10 | 7/16″ | .035′ |
| 11 | ½″ | .042′ |
| 12 | ⅝″ | .050′ |
| 13 | 11/16″ | .059′ |
| 14 | 13/16″ | .068′ |
| 15 | 15/16″ | .078′ |
| 16 | 1 1/16″ | .089′ |
| 17 | 1 3/16″ | .100′ |
| 18 | 1⅜″ | .112′ |
| 19 | 1½″ | .125′ |
| 20 | 1 11/16″ | .139′ |
| 21 | 1 13/16″ | .153′ |
| 22 | 2″ | .168′ |
| 23 | 2 3/16″ | .184′ |
| 24 | 2⅜″ | .200′ |
| 25 | 2⅝″ | .217′ |
| 26 | 2 13/16″ | .235′ |
| 27 | 3 1/16″ | .253′ |
| 28 | 3¼″ | .272′ |
| 29 | 3½″ | .292′ |
| 30 | 3¾″ | .312′ |

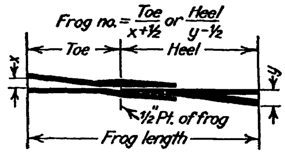


Example

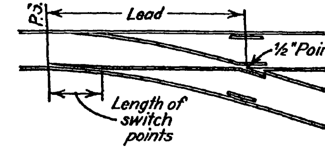



Turnout

Crossover




Frog Detail




Split-switch Turnout

## TABLE 15. FROGS, SWITCHES, TURNOUTS, AND CROSSOVERS

| Frog No. | Frogs | | Switches | | Turnouts and Crossovers | | | | | | | | | | | | | | | Q Columns A and C below give the amounts to add to tabular figures for every 0.1 ft. increase in distance between tracks. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Distance in Feet between Center Lines of Tracks. Gage—4′-8½″ | | | | | | | | | | | | | | | | |
| | Frog Angle | Frog Length | Length of Switch Points | Lead Distance from Pt. of Switch to ½″ Pt. of Frog | 12′-0″ | | | 13′-0″ | | | 14′-0″ | | | 16′-0″ | | | 18′-0″ | | | | |
| | | | | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | C |
| 6 | 9°-31′-38″ | 11′-4½″ | 11′-0″ | 48.19 | 14.50 | 16.23 | 72.50 | 20.46 | 22.07 | 78.54 | 26.42 | 28.00 | 84.58 | 38.33 | 39.96 | 96.67 | 50.24 | 51.97 | 108.75 | .596 | .604 |
| 7 | 8°-10′-16″ | 14′-7½″ | 16′-6″ | 61.28 | 17.07 | 18.57 | 84.43 | 24.04 | 25.43 | 91.47 | 31.00 | 32.36 | 98.50 | 44.93 | 46.33 | 112.57 | 58.85 | 60.33 | 126.14 | .696 | .704 |
| 8 | 7°-09′-10″ | 15′-5″ | 16′-6″ | 67.14 | 19.63 | 20.93 | 96.37 | 27.60 | 28.82 | 104.40 | 35.57 | 36.76 | 112.44 | 51.51 | 52.73 | 128.50 | 67.45 | 68.75 | 144.56 | .797 | .804 |
| 9 | 6°-21′-35″ | 16′-3″ | 16′-6″ | 72.73 | 22.17 | 23.34 | 108.33 | 31.14 | 32.21 | 117.36 | 40.12 | 41.18 | 126.39 | 58.07 | 59.16 | 144.44 | 76.02 | 77.17 | 162.50 | .898 | .903 |
| 10 | 5°-43′-29″ | 17′-10½″ | 16′-6″ | 77.61 | 24.71 | 25.76 | 120.30 | 34.68 | 35.65 | 130.33 | 44.66 | 45.61 | 140.35 | 64.61 | 65.59 | 160.40 | 84.56 | 85.60 | 180.45 | .998 | 1.003 |
| 12 | 4°-46′-19″ | 20′-4″ | 22′-0″ | 97.25 | 29.76 | 30.64 | 144.25 | 41.73 | 42.54 | 156.27 | 53.71 | 54.51 | 168.29 | 77.67 | 78.49 | 192.33 | 101.62 | 102.49 | 216.37 | 1.198 | 1.202 |
| 14 | 4°-05′-27″ | 23′-7″ | 22′-0″ | 107.33 | 34.80 | 35.54 | 168.21 | 48.78 | 49.49 | 182.23 | 62.76 | 63.44 | 196.25 | 90.73 | 91.43 | 224.28 | 118.69 | 119.43 | 252.32 | 1.398 | 1.402 |
| 16 | 3°-34′-47″ | 26′-0″ | 30′-0″ | 131.36 | 39.82 | 40.47 | 192.19 | 55.81 | 56.42 | 208.21 | 71.79 | 72.39 | 224.23 | 103.76 | 104.37 | 256.26 | 135.73 | 136.38 | 288.29 | 1.598 | 1.602 |
| 18 | 3°-10′-56″ | 29′-3″ | 30′-0″ | 141.14 | 44.85 | 45.44 | 216.17 | 62.84 | 63.38 | 234.19 | 80.82 | 81.36 | 252.20 | 116.79 | 117.33 | 288.23 | 152.76 | 153.34 | 324.26 | 1.798 | 1.802 |

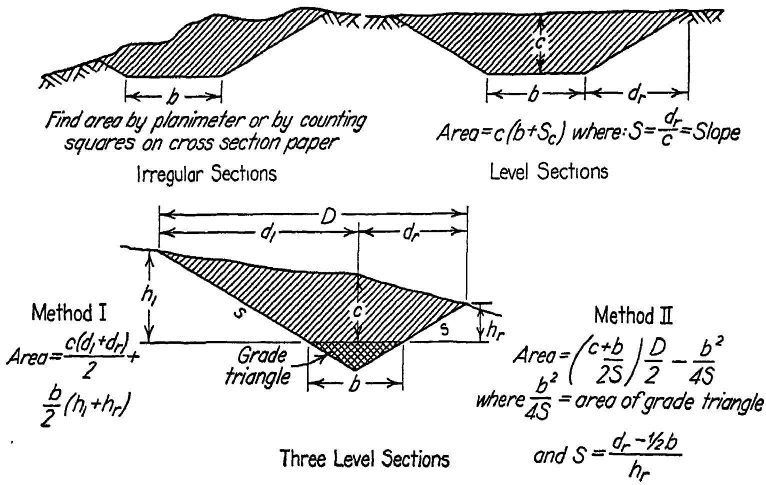


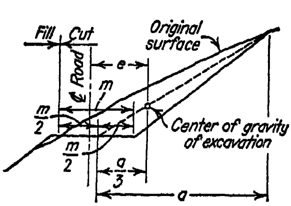

FIG. 18. Methods of finding areas.

1. By average end areas:* Volume in cubic yards $= \dfrac{A_0 + A_1}{2} \cdot \dfrac{l}{27}$, where $l$ = distance in feet between section $A_0$ and $A_1$. Compute end areas as indicated in Fig. 18. Use Tables 16 and 17; also see example on p. 235.

2. By prismoidal formula: Volume in cubic yards $= \dfrac{A_0 + 4M + A_1}{6} \cdot \dfrac{l}{27}$, where $l$ = distance in feet between sections $A_0$ and $A_1$, $M$ = area at section midway between section $A_0$ and $A_1$.

3. Using prismoidal corrections: Subtract volume in Table 18, p. 240, from volume found using average end areas method.

4. To find volume of excavation on curves use average end area method with $l$ between sections as indicated below. Fill volumes can be computed similarly.




$l$ = distance between centers of gravity of adjacent sections.

Locate c.g. as shown on left; plot $e$ on plan, and scale $l$ along curve as indicated at right.

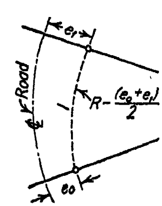
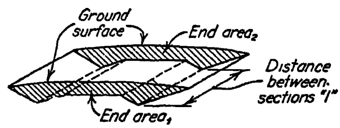



FIG. 19. Methods of finding volumes.

* Used by most state highway departments and Public Roads Administration. Recommended for roads and airports.




EXAMPLE 1. *Given.* End area$_1$ = 97 sq. ft.; end area$_2$ = 120 sq. ft.; $l$ = 50′.

*Required.* Cubic yards between sections.

*Solution.* D.A. = 97 + 120 = 217 sq. ft. Enter D.A. column, and to right of 217 find C.Y. = 201 in C.Y. column.

Use Table 17 for D.A. of from 500 to 1000 cu. yd.

EXAMPLE 2. *Given.* D.A. = 2751 sq. ft.; $l$ = 50′.

*Required.* Cubic yards between stations.

*Solution.* D.A. of 2000 = 1852 cu. yd. Find at bottom of Table 16; D.A. of 751 sq. ft. = 695 cu. yd. Therefore cubic yards for D.A. of 2751 sq. ft. = 1852 + 695 = 2547 cu. yd.

EXAMPLE 3. When $l$ is less than 50′.

*Given.* D.A. = 217 sq. ft.; $l$ = 37′.

*Required.* C.Y. between sections.

*Solution.* Enter column "Distance between Sections" and to right of 37 find "Constant" .6852. Then .6852 × 217 = 149 C.Y.

DOUBLE END AREA VOLUMES

TABLE 16. CUBIC YARDS FOR SUM OF END AREAS FOR DISTANCE BETWEEN STATIONS OF 50 FT. *

D.A. = sum of end areas in square feet.

| D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | Distance between Sections | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 50 | 46 | 100 | 93 | 150 | 139 | 200 | 185 | 250 | 231 | 300 | 278 | 350 | 324 | 400 | 370 | 450 | 417 | 0′ | .0000 |
| 1 | 1 | 51 | 47 | 101 | 94 | 151 | 140 | 201 | 186 | 251 | 232 | 301 | 279 | 351 | 325 | 401 | 371 | 451 | 418 | 1′ | .0185 |
| 2 | 2 | 52 | 48 | 102 | 94 | 152 | 141 | 202 | 187 | 252 | 233 | 302 | 280 | 352 | 326 | 402 | 372 | 452 | 419 | 2′ | .0370 |
| 3 | 3 | 53 | 49 | 103 | 95 | 153 | 142 | 203 | 188 | 253 | 234 | 303 | 281 | 353 | 327 | 403 | 373 | 453 | 419 | 3′ | .0556 |
| 4 | 4 | 54 | 50 | 104 | 96 | 154 | 143 | 204 | 189 | 254 | 235 | 304 | 281 | 354 | 328 | 404 | 374 | 454 | 420 | 4′ | .0741 |
| 5 | 5 | 55 | 51 | 105 | 97 | 155 | 144 | 205 | 190 | 255 | 236 | 305 | 282 | 355 | 329 | 405 | 375 | 455 | 421 | 5′ | .0926 |
| 6 | 6 | 56 | 52 | 106 | 98 | 156 | 144 | 206 | 191 | 256 | 237 | 306 | 283 | 356 | 330 | 406 | 376 | 456 | 422 | 6′ | .1111 |
| 7 | 7 | 57 | 53 | 107 | 99 | 157 | 145 | 207 | 192 | 257 | 238 | 307 | 284 | 357 | 331 | 407 | 377 | 457 | 423 | 7′ | .1296 |
| 8 | 7 | 58 | 54 | 108 | 100 | 158 | 146 | 208 | 193 | 258 | 239 | 308 | 285 | 358 | 331 | 408 | 378 | 458 | 424 | 8′ | .1482 |
| 9 | 8 | 59 | 55 | 109 | 101 | 159 | 147 | 209 | 194 | 259 | 240 | 309 | 286 | 359 | 332 | 409 | 379 | 459 | 425 | 9′ | .1667 |
| 10 | 9 | 60 | 56 | 110 | 102 | 160 | 148 | 210 | 194 | 260 | 241 | 310 | 287 | 360 | 333 | 410 | 380 | 460 | 426 | 10′ | .1852 |
| 11 | 10 | 61 | 56 | 111 | 103 | 161 | 149 | 211 | 195 | 261 | 242 | 311 | 288 | 361 | 334 | 411 | 381 | 461 | 427 | 11′ | .2037 |
| 12 | 11 | 62 | 57 | 112 | 104 | 162 | 150 | 212 | 196 | 262 | 243 | 312 | 289 | 362 | 335 | 412 | 381 | 462 | 428 | 12′ | .2222 |
| 13 | 12 | 63 | 58 | 113 | 105 | 163 | 151 | 213 | 197 | 263 | 244 | 313 | 290 | 363 | 336 | 413 | 382 | 463 | 429 | 13′ | .2407 |
| 14 | 13 | 64 | 59 | 114 | 106 | 164 | 152 | 214 | 198 | 264 | 244 | 314 | 291 | 364 | 337 | 414 | 383 | 464 | 430 | 14′ | .2593 |
| 15 | 14 | 65 | 60 | 115 | 106 | 165 | 153 | 215 | 199 | 265 | 245 | 315 | 292 | 365 | 338 | 415 | 384 | 465 | 431 | 15′ | .2778 |
| 16 | 15 | 66 | 61 | 116 | 107 | 166 | 154 | 216 | 200 | 266 | 246 | 316 | 293 | 366 | 339 | 416 | 385 | 466 | 431 | 16′ | .2963 |
| 17 | 16 | 67 | 62 | 117 | 108 | 167 | 155 | 217 | 201 | 267 | 247 | 317 | 294 | 367 | 340 | 417 | 386 | 467 | 432 | 17′ | .3148 |
| 18 | 17 | 68 | 63 | 118 | 109 | 168 | 156 | 218 | 202 | 268 | 248 | 318 | 294 | 368 | 341 | 418 | 387 | 468 | 433 | 18′ | .3333 |
| 19 | 18 | 69 | 64 | 119 | 110 | 169 | 156 | 219 | 203 | 269 | 249 | 319 | 295 | 369 | 342 | 419 | 388 | 469 | 434 | 19′ | .3519 |
| 20 | 19 | 70 | 65 | 120 | 111 | 170 | 157 | 220 | 204 | 270 | 250 | 320 | 296 | 370 | 343 | 420 | 389 | 470 | 435 | 20′ | .3704 |
| 21 | 19 | 71 | 66 | 121 | 112 | 171 | 158 | 221 | 205 | 271 | 251 | 321 | 297 | 371 | 344 | 421 | 390 | 471 | 436 | 21′ | .3889 |
| 22 | 20 | 72 | 67 | 122 | 113 | 172 | 159 | 222 | 206 | 272 | 252 | 322 | 298 | 372 | 344 | 422 | 391 | 472 | 437 | 22′ | .4074 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 21 | 73 | 68 | 123 | 114 | 173 | 160 | 223 | 206 | 273 | 253 | 323 | 299 | 373 | 345 | 423 | 392 | 473 | 438 | 23′ | .4259 |
| 24 | 22 | 74 | 69 | 124 | 115 | 174 | 161 | 224 | 207 | 274 | 254 | 324 | 300 | 374 | 346 | 424 | 393 | 474 | 439 | 24′ | .4445 |
| 25 | 23 | 75 | 69 | 125 | 116 | 175 | 162 | 225 | 208 | 275 | 255 | 325 | 301 | 375 | 347 | 425 | 394 | 475 | 440 | 25′ | .4630 |
| 26 | 24 | 76 | 70 | 126 | 117 | 176 | 163 | 226 | 209 | 276 | 256 | 326 | 302 | 376 | 348 | 426 | 394 | 476 | 441 | 26′ | .4815 |
| 27 | 25 | 77 | 71 | 127 | 118 | 177 | 164 | 227 | 210 | 277 | 256 | 327 | 303 | 377 | 349 | 427 | 395 | 477 | 442 | 27′ | .5000 |
| 28 | 26 | 78 | 72 | 128 | 119 | 178 | 165 | 228 | 211 | 278 | 257 | 328 | 304 | 378 | 350 | 428 | 396 | 478 | 443 | 28′ | .5185 |
| 29 | 27 | 79 | 73 | 129 | 119 | 179 | 166 | 229 | 212 | 279 | 258 | 329 | 305 | 379 | 351 | 429 | 397 | 479 | 444 | 29′ | .5370 |
| 30 | 28 | 80 | 74 | 130 | 120 | 180 | 167 | 230 | 213 | 280 | 259 | 330 | 306 | 380 | 352 | 430 | 398 | 480 | 444 | 30′ | .5556 |
| 31 | 29 | 81 | 75 | 131 | 121 | 181 | 168 | 231 | 214 | 281 | 260 | 331 | 306 | 381 | 353 | 431 | 399 | 481 | 445 | 31′ | .5741 |
| 32 | 30 | 82 | 76 | 132 | 122 | 182 | 169 | 232 | 215 | 282 | 261 | 332 | 307 | 382 | 354 | 432 | 400 | 482 | 446 | 32′ | .5926 |
| 33 | 31 | 83 | 77 | 133 | 123 | 183 | 169 | 233 | 216 | 283 | 262 | 333 | 308 | 383 | 355 | 433 | 401 | 483 | 447 | 33′ | .6111 |
| 34 | 31 | 84 | 78 | 134 | 124 | 184 | 170 | 234 | 217 | 284 | 263 | 334 | 309 | 384 | 356 | 434 | 402 | 484 | 448 | 34′ | .6296 |
| 35 | 32 | 85 | 79 | 135 | 125 | 185 | 171 | 235 | 218 | 285 | 264 | 335 | 310 | 385 | 356 | 435 | 403 | 485 | 449 | 35′ | .6482 |
| 36 | 33 | 86 | 80 | 136 | 126 | 186 | 172 | 236 | 219 | 286 | 265 | 336 | 311 | 386 | 357 | 436 | 404 | 486 | 450 | 36′ | .6667 |
| 37 | 34 | 87 | 81 | 137 | 127 | 187 | 173 | 237 | 219 | 287 | 266 | 337 | 312 | 387 | 358 | 437 | 405 | 487 | 451 | 37′ | .6852 |
| 38 | 35 | 88 | 81 | 138 | 128 | 188 | 174 | 238 | 220 | 288 | 267 | 338 | 313 | 388 | 359 | 438 | 406 | 488 | 452 | 38′ | .7037 |
| 39 | 36 | 89 | 82 | 139 | 129 | 189 | 175 | 239 | 221 | 289 | 268 | 339 | 314 | 389 | 360 | 439 | 406 | 489 | 453 | 39′ | .7222 |
| 40 | 37 | 90 | 83 | 140 | 130 | 190 | 176 | 240 | 222 | 290 | 269 | 340 | 315 | 390 | 361 | 440 | 407 | 490 | 454 | 40′ | .7408 |
| 41 | 38 | 91 | 84 | 141 | 131 | 191 | 177 | 241 | 223 | 291 | 269 | 341 | 316 | 391 | 362 | 441 | 408 | 491 | 455 | 41′ | .7593 |
| 42 | 39 | 92 | 85 | 142 | 131 | 192 | 178 | 242 | 224 | 292 | 270 | 342 | 317 | 392 | 363 | 442 | 409 | 492 | 456 | 42′ | .7778 |
| 43 | 40 | 93 | 86 | 143 | 132 | 193 | 179 | 243 | 225 | 293 | 271 | 343 | 318 | 393 | 364 | 443 | 410 | 493 | 456 | 43′ | .7963 |
| 44 | 41 | 94 | 87 | 144 | 133 | 194 | 180 | 244 | 226 | 294 | 272 | 344 | 319 | 394 | 365 | 444 | 411 | 494 | 457 | 44′ | .8148 |
| 45 | 42 | 95 | 88 | 145 | 134 | 195 | 181 | 245 | 227 | 295 | 273 | 345 | 319 | 395 | 366 | 445 | 412 | 495 | 458 | 45′ | .8333 |
| 46 | 43 | 96 | 89 | 146 | 135 | 196 | 181 | 246 | 228 | 296 | 274 | 346 | 320 | 396 | 367 | 446 | 413 | 496 | 459 | 46′ | .8519 |
| 47 | 44 | 97 | 90 | 147 | 136 | 197 | 182 | 247 | 229 | 297 | 275 | 347 | 321 | 397 | 368 | 447 | 414 | 497 | 460 | 47′ | .8704 |
| 48 | 44 | 98 | 91 | 148 | 137 | 198 | 183 | 248 | 230 | 298 | 276 | 348 | 322 | 398 | 369 | 448 | 415 | 498 | 461 | 48′ | .8889 |
| 49 | 45 | 99 | 92 | 149 | 138 | 199 | 184 | 249 | 231 | 299 | 277 | 349 | 323 | 399 | 369 | 449 | 416 | 499 | 462 | 49′ | .9074 |
| | | | | | | | | | | | | | | | | | | 500 | 463 | 50′ | .9259 |

1000 = 926 2000 = 1852 3000 = 2778 4000 = 3704 5000 = 4630

* Based on average end area formula. Not as accurate as prismoidal formula, but as accurate as usual field measurements warrant. Specified for payment quantities by most state highway departments.

TABLE 17. CUBIC YARDS FOR SUM OF END AREAS FOR DISTANCE BETWEEN STATIONS OF 50 FT.*

D.A. = sum of end areas in square feet (double end area).

| D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | D.A. | C.Y. | Distance between Sections | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 463 | 550 | 509 | 600 | 556 | 650 | 602 | 700 | 648 | 750 | 694 | 800 | 741 | 850 | 787 | 900 | 833 | 950 | 880 | 1 | 0.0185 |
| 501 | 464 | 551 | 510 | 601 | 556 | 651 | 603 | 701 | 649 | 751 | 695 | 801 | 742 | 851 | 788 | 901 | 834 | 951 | 881 | 2 | 0.0370 |
| 502 | 465 | 552 | 511 | 602 | 557 | 652 | 604 | 702 | 650 | 752 | 696 | 802 | 743 | 852 | 789 | 902 | 835 | 952 | 881 | 3 | 0.0556 |
| 503 | 466 | 553 | 512 | 603 | 558 | 653 | 605 | 703 | 651 | 753 | 697 | 803 | 744 | 853 | 790 | 903 | 836 | 953 | 882 | 4 | 0.0741 |
| 504 | 467 | 554 | 513 | 604 | 559 | 654 | 606 | 704 | 652 | 754 | 698 | 804 | 744 | 854 | 791 | 904 | 837 | 954 | 883 | 5 | 0.0926 |
| 505 | 468 | 555 | 514 | 605 | 560 | 655 | 606 | 705 | 653 | 755 | 699 | 805 | 745 | 855 | 792 | 905 | 838 | 955 | 884 | 6 | 0.1111 |
| 506 | 469 | 556 | 515 | 606 | 561 | 656 | 607 | 706 | 654 | 756 | 700 | 806 | 746 | 856 | 793 | 906 | 839 | 956 | 885 | 7 | 0.1296 |
| 507 | 469 | 557 | 516 | 607 | 562 | 657 | 608 | 707 | 655 | 757 | 701 | 807 | 747 | 857 | 794 | 907 | 840 | 957 | 886 | 8 | 0.1482 |
| 508 | 470 | 558 | 517 | 608 | 563 | 658 | 609 | 708 | 656 | 758 | 702 | 808 | 748 | 858 | 794 | 908 | 841 | 958 | 887 | 9 | 0.1667 |
| 509 | 471 | 559 | 518 | 609 | 564 | 659 | 610 | 709 | 656 | 759 | 703 | 809 | 749 | 859 | 795 | 909 | 842 | 959 | 888 | 10 | 0.1852 |
| 510 | 472 | 560 | 519 | 610 | 565 | 660 | 611 | 710 | 657 | 760 | 704 | 810 | 750 | 860 | 796 | 910 | 843 | 960 | 889 | 11 | 0.2037 |
| 511 | 473 | 561 | 519 | 611 | 566 | 661 | 612 | 711 | 658 | 761 | 705 | 811 | 751 | 861 | 797 | 911 | 844 | 961 | 890 | 12 | 0.2222 |
| 512 | 474 | 562 | 520 | 612 | 567 | 662 | 613 | 712 | 659 | 762 | 706 | 812 | 752 | 862 | 798 | 912 | 844 | 962 | 891 | 13 | 0.2407 |
| 513 | 475 | 563 | 521 | 613 | 568 | 663 | 614 | 713 | 660 | 763 | 706 | 813 | 753 | 863 | 799 | 913 | 845 | 963 | 892 | 14 | 0.2593 |
| 514 | 476 | 564 | 522 | 614 | 569 | 664 | 615 | 714 | 661 | 764 | 707 | 814 | 754 | 864 | 800 | 914 | 846 | 964 | 893 | 15 | 0.2778 |
| 515 | 477 | 565 | 523 | 615 | 569 | 665 | 616 | 715 | 662 | 765 | 708 | 815 | 755 | 865 | 801 | 915 | 847 | 965 | 894 | 16 | 0.2963 |
| 516 | 478 | 566 | 524 | 616 | 570 | 666 | 617 | 716 | 663 | 766 | 709 | 816 | 756 | 866 | 802 | 916 | 848 | 966 | 894 | 17 | 0.3148 |
| 517 | 479 | 567 | 525 | 617 | 571 | 667 | 618 | 717 | 664 | 767 | 710 | 817 | 756 | 867 | 803 | 917 | 849 | 967 | 895 | 18 | 0.3333 |
| 518 | 480 | 568 | 526 | 618 | 572 | 668 | 619 | 718 | 665 | 768 | 711 | 818 | 757 | 868 | 804 | 918 | 850 | 968 | 896 | 19 | 0.3519 |
| 519 | 481 | 569 | 527 | 619 | 573 | 669 | 619 | 719 | 666 | 769 | 712 | 819 | 758 | 869 | 805 | 919 | 851 | 969 | 897 | 20 | 0.3704 |
| 520 | 481 | 570 | 528 | 620 | 574 | 670 | 620 | 720 | 667 | 770 | 713 | 820 | 759 | 870 | 806 | 920 | 852 | 970 | 898 | 21 | 0.3889 |
| 521 | 482 | 571 | 529 | 621 | 575 | 671 | 621 | 721 | 668 | 771 | 714 | 821 | 760 | 871 | 806 | 921 | 853 | 971 | 899 | 22 | 0.4074 |
| 522 | 483 | 572 | 530 | 622 | 576 | 672 | 622 | 722 | 669 | 772 | 715 | 822 | 761 | 872 | 807 | 922 | 854 | 972 | 900 | 23 | 0.4259 |
| 523 | 484 | 573 | 531 | 623 | 577 | 673 | 623 | 723 | 669 | 773 | 716 | 823 | 762 | 873 | 808 | 923 | 855 | 973 | 901 | 24 | 0.4445 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 524 | 485 | 574 | 531 | 624 | 578 | 674 | 624 | 724 | 670 | 774 | 717 | 824 | 763 | 874 | 809 | 924 | 856 | 974 | 902 | 25 | 0.4630 |
| 525 | 486 | 575 | 532 | 625 | 579 | 675 | 625 | 725 | 671 | 775 | 718 | 825 | 764 | 875 | 810 | 925 | 856 | 975 | 903 | 26 | 0.4815 |
| 526 | 487 | 576 | 533 | 626 | 580 | 676 | 626 | 726 | 672 | 776 | 719 | 826 | 765 | 876 | 811 | 926 | 857 | 976 | 904 | 27 | 0.5000 |
| 527 | 488 | 577 | 534 | 627 | 581 | 677 | 627 | 727 | 673 | 777 | 719 | 827 | 766 | 877 | 812 | 927 | 858 | 977 | 905 | 28 | 0.5185 |
| 528 | 489 | 578 | 535 | 628 | 581 | 678 | 628 | 728 | 674 | 778 | 720 | 828 | 767 | 878 | 813 | 928 | 859 | 978 | 906 | 29 | 0.5370 |
| 529 | 490 | 579 | 536 | 629 | 582 | 679 | 629 | 729 | 675 | 779 | 721 | 829 | 768 | 879 | 814 | 929 | 860 | 979 | 906 | 30 | 0.5556 |
| 530 | 491 | 580 | 537 | 630 | 583 | 680 | 630 | 730 | 676 | 780 | 722 | 830 | 769 | 880 | 815 | 930 | 861 | 980 | 907 | 31 | 0.5741 |
| 531 | 492 | 581 | 538 | 631 | 584 | 681 | 631 | 731 | 677 | 781 | 723 | 831 | 769 | 881 | 816 | 931 | 862 | 981 | 908 | 32 | 0.5926 |
| 532 | 493 | 582 | 539 | 632 | 585 | 682 | 631 | 732 | 678 | 782 | 724 | 832 | 770 | 882 | 817 | 932 | 863 | 982 | 909 | 33 | 0.6111 |
| 533 | 494 | 583 | 540 | 633 | 586 | 683 | 632 | 733 | 679 | 783 | 725 | 833 | 771 | 883 | 818 | 933 | 864 | 983 | 910 | 34 | 0.6296 |
| 534 | 494 | 584 | 541 | 634 | 587 | 684 | 633 | 734 | 680 | 784 | 726 | 834 | 772 | 884 | 819 | 934 | 865 | 984 | 911 | 35 | 0.6482 |
| 535 | 495 | 585 | 542 | 635 | 588 | 685 | 634 | 735 | 681 | 785 | 727 | 835 | 773 | 885 | 819 | 935 | 866 | 985 | 912 | 36 | 0.6667 |
| 536 | 496 | 586 | 543 | 636 | 589 | 686 | 635 | 736 | 681 | 786 | 728 | 836 | 774 | 886 | 820 | 936 | 867 | 986 | 913 | 37 | 0.6852 |
| 537 | 497 | 587 | 544 | 637 | 590 | 687 | 636 | 737 | 682 | 787 | 729 | 837 | 775 | 887 | 821 | 937 | 868 | 987 | 914 | 38 | 0.7037 |
| 538 | 498 | 588 | 544 | 638 | 591 | 688 | 637 | 738 | 683 | 788 | 730 | 838 | 776 | 888 | 822 | 938 | 869 | 988 | 915 | 39 | 0.7222 |
| 539 | 499 | 589 | 545 | 639 | 592 | 689 | 638 | 739 | 684 | 789 | 731 | 839 | 777 | 889 | 823 | 939 | 869 | 989 | 916 | 40 | 0.7408 |
| 540 | 500 | 590 | 546 | 640 | 593 | 690 | 639 | 740 | 685 | 790 | 731 | 840 | 778 | 890 | 824 | 940 | 870 | 990 | 917 | 41 | 0.7593 |
| 541 | 501 | 591 | 547 | 641 | 593 | 691 | 640 | 741 | 686 | 791 | 732 | 841 | 779 | 891 | 825 | 941 | 871 | 991 | 918 | 42 | 0.7778 |
| 542 | 502 | 592 | 548 | 642 | 594 | 692 | 641 | 742 | 687 | 792 | 733 | 842 | 780 | 892 | 826 | 942 | 872 | 992 | 919 | 43 | 0.7963 |
| 543 | 503 | 593 | 549 | 643 | 595 | 693 | 642 | 743 | 688 | 793 | 734 | 843 | 781 | 893 | 827 | 943 | 873 | 993 | 919 | 44 | 0.8148 |
| 544 | 504 | 594 | 550 | 644 | 596 | 694 | 643 | 744 | 689 | 794 | 735 | 844 | 781 | 894 | 828 | 944 | 874 | 994 | 920 | 45 | 0.8333 |
| 545 | 505 | 595 | 551 | 645 | 597 | 695 | 644 | 745 | 690 | 795 | 736 | 845 | 782 | 895 | 829 | 945 | 875 | 995 | 921 | 46 | 0.8519 |
| 546 | 506 | 596 | 552 | 646 | 598 | 696 | 644 | 746 | 691 | 796 | 737 | 846 | 783 | 896 | 830 | 946 | 876 | 996 | 922 | 47 | 0.8704 |
| 547 | 506 | 597 | 553 | 647 | 599 | 697 | 645 | 747 | 692 | 797 | 738 | 847 | 784 | 897 | 831 | 947 | 877 | 997 | 923 | 48 | 0.8889 |
| 548 | 507 | 598 | 554 | 648 | 600 | 698 | 646 | 748 | 693 | 798 | 739 | 848 | 785 | 898 | 831 | 948 | 878 | 998 | 924 | 49 | 0.9074 |
| 549 | 508 | 599 | 555 | 649 | 601 | 699 | 647 | 749 | 694 | 799 | 740 | 849 | 786 | 899 | 832 | 949 | 879 | 999 | 925 | 50 | 0.9259 |

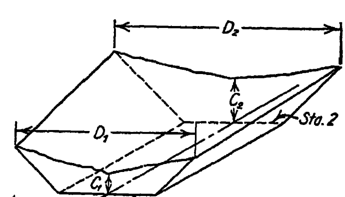
1000 = 926 2000 = 1852 3000 = 2778 4000 = 3704 5000 = 4630 6000 = 5556 7000 = 6481 8000 = 7407

* Based on average end area formula. Not as accurate as prismoidal, but as accurate as usual field measurements warrant. Specified for payment quantities by most state highway departments.

For examples illustrating use of table see p. 235.

## TABLE 18. PRISMOIDAL CORRECTIONS FOR L = 100′ STATIONS *

| $c_1 - c_2 =$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $D_1 - D_2$ | | | | | | | | | |
| 0.1 | 0.03 | 0.06 | 0.09 | 0.12 | 0.15 | 0.19 | 0.22 | 0.25 | 0.28 |
| 0.2 | 0.06 | 0.12 | 0.19 | 0.25 | 0.31 | 0.37 | 0.43 | 0.49 | 0.56 |
| 0.3 | 0.09 | 0.19 | 0.28 | 0.37 | 0.46 | 0.56 | 0.65 | 0.74 | 0.83 |
| 0.4 | 0.12 | 0.25 | 0.37 | 0.49 | 0.62 | 0.74 | 0.86 | 0.99 | 1.11 |
| 0.5 | 0.15 | 0.31 | 0.46 | 0.62 | 0.77 | 0.93 | 1.08 | 1.23 | 1.39 |
| 0.6 | 0.19 | 0.37 | 0.56 | 0.74 | 0.93 | 1.11 | 1.30 | 1.48 | 1.67 |
| 0.7 | 0.22 | 0.43 | 0.65 | 0.86 | 1.08 | 1.30 | 1.51 | 1.73 | 1.94 |
| 0.8 | 0.25 | 0.49 | 0.74 | 0.99 | 1.23 | 1.48 | 1.73 | 1.98 | 2.22 |
| 0.9 | 0.28 | 0.56 | 0.83 | 1.11 | 1.39 | 1.67 | 1.94 | 2.22 | 2.50 |
| 1.0 | 0.31 | 0.62 | 0.93 | 1.23 | 1.54 | 1.85 | 2.16 | 2.47 | 2.78 |
| 1.1 | 0.34 | 0.68 | 1.02 | 1.36 | 1.70 | 2.04 | 2.38 | 2.72 | 3.06 |
| 1.2 | 0.37 | 0.74 | 1.11 | 1.48 | 1.85 | 2.22 | 2.59 | 2.96 | 3.33 |
| 1.3 | 0.40 | 0.80 | 1.20 | 1.60 | 2.01 | 2.41 | 2.81 | 3.21 | 3.61 |
| 1.4 | 0.43 | 0.86 | 1.30 | 1.73 | 2.16 | 2.59 | 3.02 | 3.46 | 3.89 |
| 1.5 | 0.46 | 0.93 | 1.39 | 1.85 | 2.31 | 2.78 | 3.24 | 3.70 | 4.17 |
| 1.6 | 0.49 | 0.99 | 1.48 | 1.98 | 2.47 | 2.96 | 3.46 | 3.95 | 4.44 |
| 1.7 | 0.52 | 1.05 | 1.57 | 2.10 | 2.62 | 3.15 | 3.67 | 4.20 | 4.72 |
| 1.8 | 0.56 | 1.11 | 1.67 | 2.22 | 2.78 | 3.33 | 3.89 | 4.44 | 5.00 |
| 1.9 | 0.59 | 1.17 | 1.76 | 2.35 | 2.93 | 3.52 | 4.10 | 4.69 | 5.28 |
| 2.0 | 0.62 | 1.23 | 1.85 | 2.47 | 3.09 | 3.70 | 4.32 | 4.94 | 5.56 |
| 2.1 | 0.65 | 1.30 | 1.94 | 2.59 | 3.24 | 3.89 | 4.54 | 5.19 | 5.83 |
| 2.2 | 0.68 | 1.36 | 2.04 | 2.72 | 3.40 | 4.07 | 4.75 | 5.43 | 6.11 |
| 2.3 | 0.71 | 1.42 | 2.13 | 2.84 | 3.55 | 4.26 | 4.97 | 5.68 | 6.39 |
| 2.4 | 0.74 | 1.48 | 2.22 | 2.96 | 3.70 | 4.44 | 5.19 | 5.93 | 6.67 |
| 2.5 | 0.77 | 1.54 | 2.31 | 3.09 | 3.86 | 4.63 | 5.40 | 6.17 | 6.94 |
| 2.6 | 0.80 | 1.60 | 2.41 | 3.21 | 4.01 | 4.81 | 5.62 | 6.42 | 7.22 |
| 2.7 | 0.83 | 1.67 | 2.50 | 3.33 | 4.17 | 5.00 | 5.83 | 6.67 | 7.50 |
| 2.8 | 0.86 | 1.73 | 2.59 | 3.46 | 4.32 | 5.19 | 6.05 | 6.91 | 7.78 |
| 2.9 | 0.90 | 1.79 | 2.69 | 3.58 | 4.48 | 5.37 | 6.27 | 7.16 | 8.06 |
| 3.0 | 0.93 | 1.85 | 2.78 | 3.70 | 4.63 | 5.56 | 6.48 | 7.41 | 8.33 |
| 3.1 | 0.96 | 1.91 | 2.87 | 3.83 | 4.78 | 5.74 | 6.70 | 7.65 | 8.61 |
| 3.2 | 0.99 | 1.98 | 2.96 | 3.95 | 4.94 | 5.93 | 6.91 | 7.90 | 8.89 |
| 3.3 | 1.02 | 2.04 | 3.06 | 4.07 | 5.09 | 6.11 | 7.13 | 8.15 | 9.17 |
| 3.4 | 1.05 | 2.10 | 3.15 | 4.20 | 5.25 | 6.30 | 7.35 | 8.40 | 9.44 |
| 3.5 | 1.08 | 2.16 | 3.24 | 4.32 | 5.40 | 6.48 | 7.56 | 8.64 | 9.72 |
| 3.6 | 1.11 | 2.22 | 3.33 | 4.44 | 5.56 | 6.67 | 7.78 | 8.89 | 10.00 |
| 3.7 | 1.14 | 2.28 | 3.43 | 4.57 | 5.71 | 6.85 | 7.99 | 9.14 | 10.28 |
| 3.8 | 1.17 | 2.35 | 3.52 | 4.69 | 5.86 | 7.04 | 8.21 | 9.38 | 10.56 |
| 3.9 | 1.20 | 2.41 | 3.61 | 4.81 | 6.02 | 7.22 | 8.43 | 9.63 | 10.83 |
| 4.0 | 1.23 | 2.47 | 3.70 | 4.94 | 6.17 | 7.41 | 8.64 | 9.88 | 11.11 |
| 4.1 | 1.27 | 2.53 | 3.80 | 5.06 | 6.33 | 7.59 | 8.86 | 10.12 | 11.39 |
| 4.2 | 1.30 | 2.59 | 3.89 | 5.19 | 6.48 | 7.78 | 9.07 | 10.37 | 11.67 |
| 4.3 | 1.33 | 2.65 | 3.98 | 5.31 | 6.64 | 7.96 | 9.29 | 10.62 | 11.94 |
| 4.4 | 1.36 | 2.72 | 4.07 | 5.43 | 6.79 | 8.15 | 9.51 | 10.86 | 12.22 |
| 4.5 | 1.39 | 2.78 | 4.17 | 5.56 | 6.94 | 8.33 | 9.72 | 11.11 | 12.50 |
| 4.6 | 1.42 | 2.84 | 4.26 | 5.68 | 7.10 | 8.52 | 9.94 | 11.36 | 12.78 |
| 4.7 | 1.45 | 2.90 | 4.35 | 5.80 | 7.25 | 8.70 | 10.15 | 11.60 | 13.06 |
| 4.8 | 1.48 | 2.96 | 4.44 | 5.93 | 7.41 | 8.89 | 10.37 | 11.85 | 13.33 |
| 4.9 | 1.51 | 3.02 | 4.54 | 6.05 | 7.56 | 9.07 | 10.50 | 12.10 | 13.61 |
| 5.0 | 1.54 | 3.09 | 4.63 | 6.17 | 7.72 | 9.26 | 10.80 | 12.35 | 13.89 |
| $c_1 - c_2 =$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |




EXAMPLE. *Given.* $c_1 = 4'$, $D_1 = 130'$, $c_2 = 8'$, $D_2 = 138'$.

*Required.* Prismoidal correction value.

*Solution.* $c_1 - c_2 = 4$; $D_1 - D_2 = 8$. Enter table at 8.0; read correction = 9.88 cu. yd. $(c_2 - c_1)(D_2 - D_1) = (8 - 4)(138 - 130) = +$. Subtract correction from volume by average end area method. See p. 234.

## TABLE 18. PRISMOIDAL CORRECTIONS FOR L = 100′ STATIONS,* Continued

| $c_1 - c_2 =$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $D_1 - D_2$ | | | | | | | | | |
| 5.1 | 1.57 | 3.15 | 4.72 | 6.30 | 7.87 | 9.44 | 11.02 | 12.59 | 14.17 |
| 5.2 | 1.60 | 3.21 | 4.81 | 6.42 | 8.02 | 9.63 | 11.23 | 12.84 | 14.44 |
| 5.3 | 1.64 | 3.27 | 4.91 | 6.54 | 8.18 | 9.81 | 11.45 | 13.09 | 14.72 |
| 5.4 | 1.67 | 3.33 | 5.00 | 6.67 | 8.33 | 10.00 | 11.67 | 13.33 | 15.00 |
| 5.5 | 1.70 | 3.40 | 5.09 | 6.79 | 8.49 | 10.19 | 11.88 | 13.58 | 15.28 |
| 5.6 | 1.73 | 3.46 | 5.19 | 6.91 | 8.64 | 10.37 | 12.10 | 13.83 | 15.56 |
| 5.7 | 1.76 | 3.52 | 5.28 | 7.04 | 8.80 | 10.56 | 12.31 | 14.07 | 15.83 |
| 5.8 | 1.79 | 3.58 | 5.37 | 7.16 | 8.95 | 10.74 | 12.53 | 14.32 | 16.11 |
| 5.9 | 1.82 | 3.64 | 5.46 | 7.28 | 9.10 | 10.93 | 12.75 | 14.57 | 16.39 |
| 6.0 | 1.85 | 3.70 | 5.56 | 7.41 | 9.26 | 11.11 | 12.96 | 14.81 | 16.67 |
| 6.1 | 1.88 | 3.77 | 5.65 | 7.53 | 9.41 | 11.30 | 13.18 | 15.06 | 16.94 |
| 6.2 | 1.91 | 3.83 | 5.74 | 7.65 | 9.57 | 11.48 | 13.40 | 15.31 | 17.22 |
| 6.3 | 1.94 | 3.89 | 5.83 | 7.78 | 9.72 | 11.67 | 13.61 | 15.56 | 17.50 |
| 6.4 | 1.98 | 3.95 | 5.93 | 7.90 | 9.88 | 11.85 | 13.83 | 15.80 | 17.78 |
| 6.5 | 2.01 | 4.01 | 6.02 | 8.02 | 10.03 | 12.04 | 14.04 | 16.05 | 18.06 |
| 6.6 | 2.04 | 4.07 | 6.11 | 8.15 | 10.19 | 12.22 | 14.26 | 16.30 | 18.33 |
| 6.7 | 2.07 | 4.14 | 6.20 | 8.27 | 10.34 | 12.41 | 14.48 | 16.54 | 18.61 |
| 6.8 | 2.10 | 4.20 | 6.30 | 8.40 | 10.49 | 12.59 | 14.69 | 16.79 | 18.89 |
| 6.9 | 2.13 | 4.26 | 6.39 | 8.52 | 10.65 | 12.78 | 14.91 | 17.04 | 19.17 |
| 7.0 | 2.16 | 4.32 | 6.48 | 8.64 | 10.80 | 12.96 | 15.12 | 17.28 | 19.44 |
| 7.1 | 2.19 | 4.38 | 6.57 | 8.77 | 10.96 | 13.15 | 15.34 | 17.53 | 19.72 |
| 7.2 | 2.22 | 4.44 | 6.67 | 8.89 | 11.11 | 13.33 | 15.56 | 17.78 | 20.00 |
| 7.3 | 2.25 | 4.51 | 6.76 | 9.01 | 11.27 | 13.52 | 15.77 | 18.02 | 20.28 |
| 7.4 | 2.28 | 4.57 | 6.85 | 9.14 | 11.42 | 13.70 | 15.99 | 18.27 | 20.56 |
| 7.5 | 2.31 | 4.63 | 6.94 | 9.26 | 11.57 | 13.89 | 16.20 | 18.52 | 20.83 |
| 7.6 | 2.35 | 4.69 | 7.04 | 9.38 | 11.73 | 14.07 | 16.42 | 18.77 | 21.11 |
| 7.7 | 2.38 | 4.75 | 7.13 | 9.51 | 11.88 | 14.26 | 16.64 | 19.01 | 21.39 |
| 7.8 | 2.41 | 4.81 | 7.22 | 9.63 | 12.04 | 14.44 | 16.85 | 19.26 | 21.67 |
| 7.9 | 2.44 | 4.88 | 7.31 | 9.75 | 12.19 | 14.63 | 17.07 | 19.51 | 21.94 |
| 8.0 | 2.47 | 4.94 | 7.41 | 9.88 | 12.35 | 14.81 | 17.28 | 19.75 | 22.22 |
| 8.1 | 2.50 | 5.00 | 7.50 | 10.00 | 12.50 | 15.00 | 17.50 | 20.00 | 22.50 |
| 8.2 | 2.53 | 5.06 | 7.59 | 10.12 | 12.65 | 15.19 | 17.72 | 20.25 | 22.78 |
| 8.3 | 2.56 | 5.12 | 7.69 | 10.25 | 12.81 | 15.37 | 17.93 | 20.49 | 23.06 |
| 8.4 | 2.59 | 5.19 | 7.78 | 10.37 | 12.96 | 15.56 | 18.15 | 20.74 | 23.33 |
| 8.5 | 2.62 | 5.25 | 7.87 | 10.49 | 13.12 | 15.74 | 18.36 | 20.99 | 23.61 |
| 8.6 | 2.65 | 5.31 | 7.96 | 10.62 | 13.27 | 15.93 | 18.58 | 21.23 | 23.89 |
| 8.7 | 2.69 | 5.37 | 8.06 | 10.74 | 13.43 | 16.11 | 18.80 | 21.48 | 24.17 |
| 8.8 | 2.72 | 5.43 | 8.15 | 10.86 | 13.58 | 16.30 | 19.01 | 21.73 | 24.44 |
| 8.9 | 2.75 | 5.49 | 8.24 | 10.99 | 13.73 | 16.48 | 19.23 | 21.97 | 24.72 |
| 9.0 | 2.78 | 5.56 | 8.33 | 11.11 | 13.89 | 16.67 | 19.44 | 22.22 | 25.00 |
| 9.1 | 2.81 | 5.62 | 8.43 | 11.23 | 14.04 | 16.85 | 19.66 | 22.47 | 25.28 |
| 9.2 | 2.84 | 5.68 | 8.52 | 11.36 | 14.20 | 17.04 | 19.88 | 22.72 | 25.56 |
| 9.3 | 2.87 | 5.74 | 8.61 | 11.48 | 14.35 | 17.22 | 20.09 | 22.96 | 25.83 |
| 9.4 | 2.90 | 5.80 | 8.70 | 11.60 | 14.51 | 17.41 | 20.31 | 23.21 | 26.11 |
| 9.5 | 2.93 | 5.86 | 8.80 | 11.73 | 14.66 | 17.59 | 20.52 | 23.46 | 26.39 |
| 9.6 | 2.96 | 5.93 | 8.89 | 11.85 | 14.81 | 17.78 | 20.74 | 23.70 | 26.67 |
| 9.7 | 2.99 | 5.99 | 8.98 | 11.98 | 14.97 | 17.96 | 20.96 | 23.95 | 26.94 |
| 9.8 | 3.02 | 6.05 | 9.07 | 12.10 | 15.12 | 18.15 | 21.17 | 24.20 | 27.22 |
| 9.9 | 3.06 | 6.11 | 9.17 | 12.22 | 15.28 | 18.33 | 21.39 | 24.44 | 27.50 |
| 10.0 | 3.09 | 6.17 | 9.26 | 12.35 | 15.43 | 18.52 | 21.60 | 24.69 | 27.78 |
| $c_1 - c_2 =$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

$c_1$, $c_2$, $D_1$, and $D_2$ are shown for a three-level section. Volume by average end area ± prismoidal correction = volume by prismoidal formula.

When $(c_2 - c_1)(D_2 - D_1)$ is +, subtract correction.

When $(c_2 - c_1)(D_2 - D_1)$ is −, add correction.

Irregular sections are generally treated the same as three-level sections.

* *From American Civil Engineers Handbook by Merriman and Wiggin.*

## SAMPLE NOTES

April 26, 1944 - Cloudy, Cool, 50-60°F.

BENCH LEVELS

| STA. | + B.S. | H.I. | − F.S. | Elev. | Estab. Elev. |
|---|---|---|---|---|---|
| BM#6 | 4.57 | 110.13 | | | 105.56 |
| TP#1 | 3.18 | 107.18 | 6.13 | 104.00 | |
| T.P.#2 | 2.56 | 104.07 | 5.67 | 101.51 | |
| TP#3 | 5.06 | 105.05 | 4.08 | 99.99 | |
| BM#7 | 4.17 | 103.02 | 6.20 | 98.85 | |
| | | | | | |
| TP#4 | 8.11 | 105.94 | 5.19 | 97.83 | |
| TP#5 | 7.16 | 107.03 | 6.07 | 99.87 | |
| BM#8 | | | 5.55 | 101.48 | 101.47 |
| | 34.81 | | 38.89 | 105.56 | |
| | | | 34.81 | 4.08 | |
| | | | 4.08 | check | |

E. Kroyer, Level   J. Lenart, Rod

MYRTLE STREET

K&E Wye Level 2167

Concrete Monument Sta 4+16 - 56' Rt

Nail Head in Tel Pole Sta 6+50 Lt.

Top of stake " 8+25 - 50' Lt.

Top Nut Hydrant " 10+15 Rt.

□ Cut on Top N E Corner of Retaining wall

Sta 12+25 - 55.7' Rt

Point on Curb Sta 14+06 - 30' Rt

Cor. Conc. Step " 16+19 - 60' Rt.

U.S.G.S. Mon. " 18+35 - 45' Lt.

FIG. 20.

June 17, 1943 - Warm, Humid Overcast 70°-75°F

PROFILE LEVELS

| STA. | + B.S. | H.I. | − F.S. | Elev. | Estab. Elev. |
|---|---|---|---|---|---|
| | | | | | |
| B.M.2 | 4.15 | 99.82 | | | 95.67 |
| 0+00 | | | 6.2 | 93.6 | |
| 0+50 | | | 5.9 | 93.9 | |
| 0+70 | | | 4.7 | 95.1 | |
| 1+00 | | | 5.5 | 94.3 | |
| 1+25 | | | 7.0 | 92.8 | |
| 1+50 | | | 6.0 | 93.8 | |
| 2+00 | | | 5.3 | 94.5 | |
| 2+20 | | | 5.5 | 94.3 | |
| 2+28 | | | 9.7 | 90.1 | |
| 2+34 | | | 9.9 | 89.9 | |
| 2+44 | | | 5.0 | 94.8 | |
| 2+50 | | | 4.5 | 95.3 | |
| T.P.1 | 5.05 | 100.88 | 3.99 | 95.83 | |
| 3+00 | | | 5.6 | 95.3 | |
| 3+50 | | | 6.6 | 94.3 | |
| 4+00 | | | 6.9 | 94.0 | |
| 4+50 | | | 7.2 | 93.7 | |
| T.P.2 | 7.42 | 101.79 | 6.51 | 94.37 | |
| B.M.3 | | | 8.33 | 93.46 | 93.47 |
| | 16.62 | | 18.83 | 95.67 | |
| | | | 16.62 | 2.21 | |
| | | | 2.21 | check | |

Berger Level 3197   CRANDALL

℄ RUNWAY 3-A -   FIELD

Whitten, Level; Wiesendanger, Rod

Concrete Mon Sta 0+10 - 265' Rt. of ℄

Rock Out crop

Top of Bank

Bottom of Ditch

" " "

Top of Bank

Top of ℄ Stake - Sta 2+50

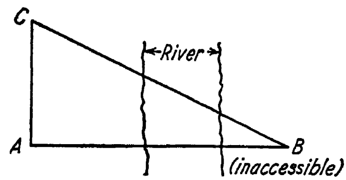
Top of ℄ Stake - Sta 4+50

Concrete Mon. Sta 5+25 - 275' Rt. of ℄

FIG. 21.

## TRANSIT PROBLEMS

### 1. Determination of Distance to Inaccessible Point




**Required.** $AB$.

**Procedure.** Set transit at $A$, sight on $B$. Turn 90° and set $C$ at a point at least equal to ½$AB$. Measure length $AC$. Set up at $C$ and measure angle $ACB$. $AB = AC \times$ tangent $ACB$.

### 2. Angles by Repetition *

**Required.** A more accurate determination of an angle than possible by a single measurement.

**Procedure.** (1) Set the transit very carefully over the point. (2) Set the $A$ vernier at zero, read the $B$ vernier, and record the readings. (3) With the telescope in its normal position, measure one of the angles in a clockwise direction, and record both vernier readings to the smallest reading of the vernier. (4) Leaving the upper motion clamped, again set on the first point and again measure the angle in a clockwise direction (thus doubling the angle). (5) Continue until six repetitions have been secured. Record both vernier readings and the total angle turned. (6) In a like manner, setting the $B$ vernier at zero, measure the explement of the angle in a counterclockwise direction with the bubble down, but read the horizontal circle as though the angle itself had been measured clockwise. (7) Go through the same process for all other angles about the point. (8) Compute the value of each of the angles for each direction turned, and compare with the single measurement. (9) Find the mean of each of these sets of single angles. For a transit reading to single minutes the total error should not exceed $10''\sqrt{n}$, in which $n$ is the number of observations. (10) Adjust the angles so that their sum shall equal 360° by distributing the error equally among the mean values.

**Hints and Precautions.** (1) Level the transit very carefully before each repetition, but do not disturb the leveling screws while a measurement is being made. (2) The mean of each set of single angles should furnish a value free from instrumental errors. The station adjustment is an attempt to distribute the accidental errors so that the condition that there are 360° about a point shall be fulfilled. (3) Do not become

* *Adapted from Davis, Manual of Surveying, McGraw-Hill,*

confused when calculating the total angle turned. Observe how the horizontal limb is graduated, and do not omit 360°. (4) The instrument should be handled very carefully. When turning on the lower motion the hands should be in contact with the lower plate (not the alidade), and when making an exact setting on a point the last movement of the tangent screw should be clockwise or against the opposing spring. (5) After each repetition the instrument should be turned on its lower motion in a direction opposite to that of the measurement. (6) The single measurement is taken as a check on the number of repetitions. It should agree closely with the mean value.

**Practical Applications.** This method is used in triangulation work to measure any angle accurately. The number of sets of readings and the number of repetitions in each set observed depend upon the desired accuracy.

### 3. Laying off Angles by Repetition *

**Required.** To lay off a given horizontal angle more accurately than by a single setting of the vernier.

**Procedure.** (1) Set the transit carefully over the point and lay off the angle. (2) Set a stake on the line of sight, preferably at least 500 ft. from the instrument, and carefully set a tack. (3) By repetition measure the angle laid off, as in the previous problem, making six repetitions in each direction. (4) Find the angular discrepancy between the angle laid off and the required angle. Move the tack perpendicular to the line of sight, a distance equal to the sine of the angular discrepancy times the measured distance between the stakes. (5) Set the tack accordingly.

**Practical Applications.** This method is of use in laying out large buildings, valuable city lots or right of ways, important highway work such as viaducts and bridges, and airport runway center lines. With a transit vernier reading to 1 minute, an error of 30 in. in a single reading might easily occur; in 300 ft. this would amount to approximately ½ in.

### 4. Area by Double Meridian Distance *

**Required.** Area of a closed traverse.

**Rules.**

Latitude = distance times cosine bearing angle.

Departure = distance times sine bearing angle.

Latitudes and departures are positive or negative according as they are north and east or south and west.

In any closed traverse the algebraic sum of the latitudes (or departures) must equal zero.

Compass rule for balancing. The correction to be applied to the lati-

* *Adapted from Davis, Manual of Surveying, McGraw-Hill.*

tude (or departure) of any course is to the total error in latitude (or departure) as the length of the course is to the perimeter of the field.

Transit rule for balancing. The correction to be applied to the latitude (or departure) of any course is to the total error in latitude (or departure) as the latitude (or departure) of that course is to the arithmetical sum of all the latitudes (or departures).

Rules for double meridian distances. (1) The D.M.D. of the first course equals the departure of that course.

(2) The D.M.D. of any other course equals the D.M.D. of the preceding course plus the departure of the preceding course plus the departure of the course itself.

(3) The D.M.D. of the last course is numerically equal to the departure of that course, but with opposite sign.

**Procedure.** (1) Transcribe necessary data from the field book into a form similar to that shown below. Check the copy.

(2) Calculate the latitude and departure of each course, using logarithms as shown in sample computations or more quickly and accurately with natural functions and a calculating machine if one is available. Check results with the slide rule.

(3) Determine the total error in latitude and in departure, and compute the error of closure.

(4) Determine the latitude and departure corrections by one of the preceding rules for balancing.

(5) Apply these corrections, and check by taking the algebraic sum of the corrected latitudes and the algebraic sum of the corrected departures. Each of these sums should equal zero.

(6) From the corrected departures compute the D.M.D.'s, applying the preceding rules and starting from the most westerly point in the survey. If the last D.M.D. is not numerically equal to the last corrected departure, it will indicate that a mistake in addition has been made.

(7) Compute double areas by the preceding rule paying special attention to signs. Check computations.

(8) Sum up the double areas, divide by 2, and transform into acres.

**Hints and Precautions.** (1) Use tables of logarithms or natural functions with number of places consistent with the precision of the field measurements. If the bearings have been determined with the surveyor's compass, four places will be sufficient; if angles have been taken to the nearest minute (in error less than 30 seconds) with the transit, five-place tables should be used.

(2) Checks should be applied after each of the steps in the computations. An absolute check on the work can, of course, be had only by recomputation, by methods that will give as many significant figures in the final result as the original computations gave. However, the slide rule will furnish an approximate check, which is very desirable.

(3) If, after having calculated the latitudes and departures and after having checked them against large errors, the error of closure is found to be larger than that allowable, the computer may frequently locate the mistake, whether it be in computations or field work, through the relation of total error in latitudes and total error in departures. Thus, if the mistake is in the length of one line and there are no other large errors, the ratio of the total error in departures to the total error in latitudes will approximately express the tangent of the bearing angle of that line, or if a mistake has been made in the latitude of a line the departures may nearly close. The computer should, therefore, conduct a critical examination of results and should then recompute those values that seem most likely to contain the mistake. If the mistake is not brought to light when all latitudes and departures have been rechecked, then, and only then, may he be warranted in concluding that the mistake occurred in the field.

(4) The compass rule or transit rule will be used for balancing latitudes and departures according as the error is assumed to be as much in angles as in distances or as the error is assumed to be mostly due to erroneous lengths.

(5) When the error of closure is small, the latitudes and departures may usually be balanced by inspection without computing the corrections by either of the preceding rules. When the computer knows the conditions surrounding the field work, he may often distribute the error according to his own judgment rather than by any fixed rule.

(6) Often neither calculated nor magnetic bearings of lines are shown in the transit notes. If deflection or interior angles were taken, it will be convenient to assume one of the lines in the traverse as the meridian and calculate the bearings of other lines accordingly. If magnetic bearings are recorded in the field notes, they should not be confused with calculated bearings and used as the basis of computations, for their precision will not warrant such use.

(7) Corrections for erroneous length of chain or tape should not be overlooked. Constant errors of this sort will have no effect on the error of closure.

(8) By starting with the most westerly point in the survey all the D.M.D.'s become positive; it is not necessary for the solution of the problem that this point be chosen, but it is customary.

**Practical Applications.** The double meridian distance method of calculating the area within a closed traverse is universally followed in preference to subdividing into triangles. It is generally agreed that it takes less time, is more systematic, and offers more easy checks; through the use of latitudes and departures, the error of closure is readily determined.

Some surveyors favor the method of double parallel distances, which is the same in principle as the preceding method, the only difference being that in double parallel distances (D.P.D.'s) the bases of trapezoids are

| Line | Cal Bear | Dist 66′ Ch. | Latitudes | | Departures | | Corrected | | D.M.Ds. | Double Areas | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | S | E | W | Lats. | Deps | | + | − |
| A−B | S 80°29½′W | 34 464 | | 5 694 | | 33.991 | − 5.693 | −33.990 | 61 812 | | 351.89 |
| B−C | S 33°04′ W | 25.493 | | 21.364 | | 13 911 | −21.361 | −13.911 | 13 911 | | 297 15 |
| C−D | S 33°46¾′E | 33.934 | | 28.205 | 18 867 | | −28 201 | +18.867 | 18 867 | | 532 06 |
| D−E | N 87°58¼′E | 28 625 | 1 013 | | 28 607 | | + 1.013 | +28 608 | 66.342 | 67 21 | |
| E−A | N 0°27′ E | 54 235 | 54.234 | | 0 426 | | +54.242 | + 0 426 | 95 376 | 5173.51 | |
| | | 176 751 | 55 247 | 55.263 | 47.900 | 47.902 | ΣL=0 | ΣD=0 | | 5240 72 | 1181.10 |
| | | | | 55.247 | | 47.900 | | | | 1181.10 | |
| | | | | .016 | | .002 | | | | 2 \| 4059.62 | |
| | | | | | | | | | | 2029.81 Sq. Ch. | |
| | | | | | | | | | | or 202.981 Ac. | |

$E.\ of\ C = \frac{.016}{176.751} = \frac{1}{11,000}$ $E = \sqrt{.016^2 + .002^2} = 0.016$ Chains.

| Line | A−B | B−C | C−D | D−E | E−A |
|---|---|---|---|---|---|
| Lat. | 5.694 | 21.364 | 28.205 | 1.013 | 54.234 |
| Log. Lat. | 0.75542 | 1.32968 | 1.45032 | 0.00584 | 1.73427 |
| Log. Cos. | 9.21805 | 9.92326 | 9 91969 | 8.54899 | 9.99999 |
| Log. Dist. | 1 53737 | 1.40642 | 1 53063 | 1.45674 | 1.73428 |
| Log. Sin. | 9.99399 | 9.73689 | 9 74509 | 9.99973 | 7.89535 |
| Log. Dep. | 1.53136 | 1 14331 | 2 27572 | 1 45647 | 9.62964 |
| Dep | 33.991 | 13 911 | 18 867 | 28.607 | 0.426 |
| Log. Cor. Lat. | 0.75534 | 1.32962 | 1.45026 | 0.00584 | 1.73434 |
| Log. D M.D. | 1 79107 | 1.14336 | 1.27570 | 1.82179 | 1.97944 |
| Log. D.A. | 2 54641 | 2 47298 | 2.72596 | 1.82763 | 3.71378 |
| Double Area | 351 89 | 297.15 | 532.06 | 67.21 | 5173.51 |

*Note:*
*Survey Balanced by Transit Rule.*

FIG. 22.

along a line perpendicular to the meridian, whereas in double meridian distances they lie on the meridian itself. Thus, the rules for finding D.M.D.'s may be changed to rules for D.P.D.'s by substituting the word "latitude" for "departure"; and the rule for finding double areas will then be as follows: The double area of any trapezoid equals the product of its D.P.D. and its corrected departure.

## 5. Omitted Side *

**Required.** Length and bearing of one side of a traverse, this side not accessible in field. (It is assumed that errors in measured sides are negligible; all errors are thrown into computed side.)

**Procedure.** (1) Calculate the latitudes and departures of the known lines as in the previous problem, and find their totals. (2) On the preceding assumption, and since the algebraic sum of latitudes and of departures for any closed traverse is zero, it follows that the latitude and departure of the unknown line are numerically equal to the sums of corresponding quantities for the known lines, but with opposite sign. Therefore, determine the bearing and length of the unknown line by the equations:

$$\text{Tan bearing angle} = \frac{\text{departure of line}}{\text{latitude of line}}$$

and

* *Adapted from Davis, Manual of Surveying, McGraw-Hill.*

Length of line $= \sqrt{\text{latitude}^2 + \text{departure}^2}$

$$= \frac{\text{latitude of line}}{\text{cos bearing angle}} = \frac{\text{departure of line}}{\text{sin bearing angle}}$$

**Precaution.** Plot known sides, and graphically check omitted side and bearing.

### 6. Prolongation of a Line by Double Sighting with Transit * (Double Centering)

**Required.** To produce a straight line with precision.

**Procedure.** (1) Set the instrument carefully over the forward point on the line with the telescope normal and backsight on line. Use the lower horizontal motion, the upper motion being clamped. (2) Plunge the telescope, and set a stake on the line in advance. Mark a point on the stake exactly on line. (3) Take a second backsight on line in the same manner as before, with the telescope inverted. Plunge the telescope again, and mark a second point on the advance stake. (4) If this point is not coincident with the first point set, a point midway between them is on the line. (5) Set the transit over this point, and advance by the same process, backsighting upon the next point in the rear. Continue in this way for the desired distance.

**Hints and Precautions.** (1) Be sure that one backsight from each station is taken with the *telescope inverted* and one with the *telescope direct.* (2) Tacks should be set in all stakes, and after being set should be checked. A finely divided scale should be used for bisecting the distances. (3) Whenever an opportunity arises, take backsights as far back on a line as possible to check the line.

**Practical Applications.** The method of double sighting is used when it is desired to set a point in advance accurately on line. The process of double sighting eliminates instrumental errors. It is used in prolonging lines of a considerable length or setting points accurately ahead on line. Frequently a line prolonged by simply plunging the telescope with a transit supposed to be in perfect adjustment has later been found to be not a straight line but a curve of large radius. The same method should be used when setting transit points ahead on a curve.

### 7. Establishing a Line by Balancing-in with Transit (Bucking-in)

**Required.** To establish an intermediate transit point on a line when the two ends of the line are not intervisible.

**Procedure.** (1) Set up the transit where the intermediate point is required, and as near as can be estimated, on the line. (2) Backsight with telescope normal on the point marking one end of the line, and plunge

* *Adapted from Davis, Manual of Surveying, McGraw-Hill.*

the telescope. (3) Move the transit a proportionate amount of the distance by which the line of sight fails to strike the point at the opposite end of the line. (4) Repeat the procedure until the line of sight is coincident with the line. (5) Establish the point by lowering the plumb bob of the transit. (6) Repeat the process with the telescope inverted as in double centering. If the instrument is not in adjustment a second point will be found; the correct point is set midway between the two.

**Hints and Precautions.** The final movement of the transit can usually be made with the shifting head. Until near the correct point, it is unnecessary to level the transit carefully. Additional points on the line can be set by direct sighting.

**8. Layout of Circular Curve**

**Required.** To establish the P.C. and P.T. of a simple curve and set points at intervals along the curve.

**Procedure.** (1) Lay off both tangents from the P.I., thus locating the P.C. and P.T. (2) Set up the transit over the P.C.; set vernier at zero and foresight on P.I. Unclamp the upper motion and sight at the P.T. if visible; the deflection angle of the long chord should equal ½ the external angle $\Delta$. (3) From the previously computed list of deflections, lay out the points on the curve using the proper deflection angle and subchord or full chord as required.

**Hints and Precautions.** (1) If the back tangent has been stationed the P.C. may be set from the nearest station. (2) When the survey is to be carried ahead the transit may be set up over the P.T. and the curve laid out from it, thus saving a set-up. (3) When setting a transit point or an accurate point on the curve (P.O.C.), the backsight should be checked and the deflection turned with the telescope plunged in both the inverted and direct positions, the point being set as in double centering for a straight line.

*Set-up on Curve.* When all the stations of a curve are not visible from either the P.C. or P.T., a transit point must be set at some point on the curve (P.O.C.) and the transit moved up to it. (1) Locate the P.O.C. (2) Set up over the P.O.C. backsight on the P.C. with a zero reading on the vernier. (3) Plunge the telescope, and turn the telescope inward until the vernier reading (deflection) for the P.O.C. is reached. The line of sight will then be tangent to the curve. (4) Lay off the deflections for the points to be set as computed in the original list.

*Note.* Any other station than the P.C. may be sighted provided the proper deflection is used. The following rules apply:

Rule I. When the transit is set on any point on a curve, an auxiliary tangent to the curve at that point may be found by sighting at any station on the curve with the deflection of the station sighted laid off on the proper side of zero and turning the upper motion until the vernier reading (deflection) for the point occupied is reached.

Rule II. When the transit is set on any point on a curve (including the P.C. or P.T.), any other point on the curve may be set by sighting at any point on the curve with the deflection for the point sighted laid off on the proper side of the vernier and turning the upper motion in the proper direction until the vernier reading (deflection) for the point to be set is reached.

SAMPLE NOTES

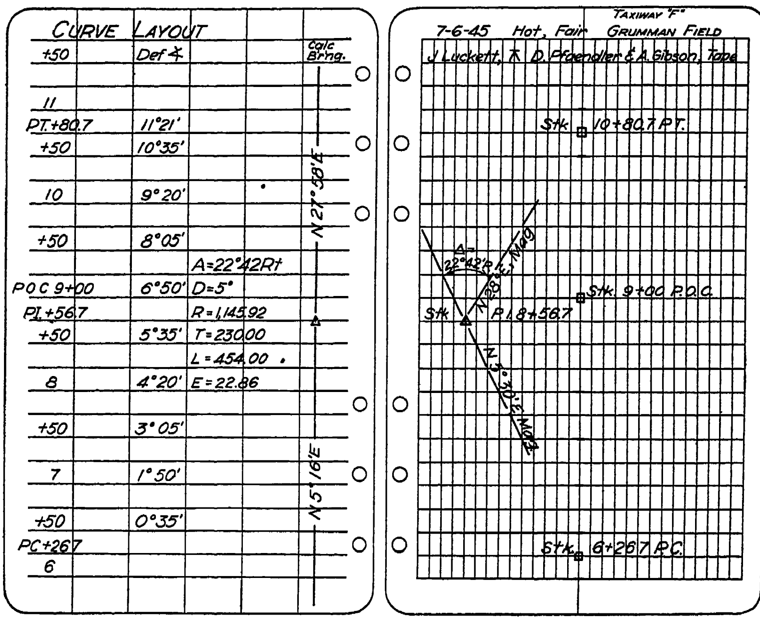



FIG. 23.

## ALLOWABLE ERRORS

### Leveling *

*Rough leveling* for rapid reconnaissance or preliminary work; sights made up to 1000 ft.; rod readings to tenths; no attention paid to balancing backsights and foresights.

Suggested maximum error in feet $= \pm 0.4\sqrt{\text{distance in miles}}$.

Ordinary leveling as required for most engineering works; maximum sights 500 ft.; rod readings to hundredths; backsights and foresights roughly balance for both length of shots and uphill and downhill work; turning points on reasonably solid objects.

Suggested maximum error in feet $= \pm 0.1\sqrt{\text{distance in miles}}$.

* *Adapted from Urquhart, Civil Engineering Handbook, McGraw-Hill.*

Accurate leveling, for principal bench marks; maximum sights 300 ft.; rod readings to thousandths; backsights and foresights paced and balanced; rod waved; bubble centered for each sight; turning points on very solid objects; level set very firmly.

Maximum error in feet $= \pm 0.05\sqrt{\text{distance in miles}}$.

This error is the same as allowed for third-order leveling, Corps of Engineers, U. S. Army.

**Distances**

By stadia, 1:750 maximum allowable error.

By tape, 1:5000 maximum allowable error for ordinary work.

**Transit and Tape Traverses**

Linear error of closure $= \sqrt{(\text{sum of latitudes})^2 + (\text{sum of departures})^2}$.

The precision of transit traverses is affected by both linear and angular errors of measurement. Many factors affect the precision, and it can be expressed only in very general terms. The following specifications give approximately the *maximum* linear and angular errors to be expected when the methods stated are followed. If the surveys are executed by well-trained men, with instruments in good adjustment, and under average field conditions, in general the error of closure should not exceed *half* the specified amount. The specifications apply to traverses of considerable length. It is assumed that a standardized tape is used.

Class 1. Precision sufficient for many preliminary surveys, for horizontal control of surveys plotted to intermediate scale, and for land surveys where the value of the land is low.

Transit angles read to the nearest minute. Sights taken on a range pole plumbed by eye. Distances measured with a 100-ft. steel tape. Pins or stakes set within 0.1 ft. of end of tape. Slopes under 3% disregarded. On slopes over 3%, distances either measured on the slope and corrections roughly applied, or measured with the tape held level and with an estimated standard pull.

Angular error of closure not to exceed $1' 30''\sqrt{n}$, in which $n$ is the number of observations. Total linear error of closure not to exceed 1/1000.

Class 2. Precision sufficient for most land surveys and for location of highways, railroads, etc. By far the greater number of transit traverses fall in this class.

Transit angles read carefully to the nearest minute. Sights taken on a range pole carefully plumbed. Pins or stakes set within 0.05 ft. of end of tape. Temperature corrections applied to the linear measurements if the temperature of air differs more than 15° F. from standard. Slopes under 2% disregarded. On slopes over 2%, distances either measured on the slope and corrections roughly applied, or measured with the tape held level and with a carefully estimated standard pull.

Angular error of closure not to exceed $1'\sqrt{n}$. Total linear error of closure not to exceed 1/3000.

Class 3. Precision sufficient for much of the work of city surveying, for surveys of important boundaries, and for the control of extensive topographic surveys.

Transit angles read twice with the instrument plunged between observations. Sights taken on a plumb line or on a range pole carefully plumbed. Pins set within 0.05 ft. of end of tape. Temperature of air determined within 10° F., and corrections applied to the linear measurements. Slopes determined within 2%, and corrections applied. Tape held level, the pull kept within 5 lb. of standard, and corrections for sag applied.

Angular error of closure not to exceed $30''\sqrt{n}$. Total linear error of closure not to exceed 1/5000.

Class 4. Precision sufficient for accurate city surveying and for other especially important surveys.

Transit angles read twice with the instrument plunged between readings, each reading being taken as the mean of both $A$ and $B$ vernier readings. Verniers reading to 30″. Instrument in excellent adjustment. Sights taken with special care. Pins set within 0.02 ft. of end of tape. Temperature of tape determined within 5° F., and corrections applied. Slopes determined within 1%, and corrections applied. Tape held level, the pull kept within 3 lb. of standard, and corrections for sag applied.

Angular error of closure not to exceed $15''\sqrt{n}$. Total linear error of closure not to exceed 1/10,000.*

## DETERMINATION OF TRUE NORTH

### OBSERVATION ON POLARIS

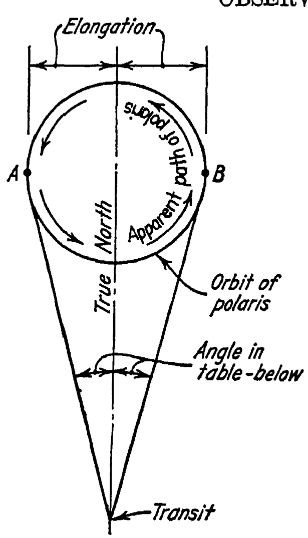



FIG. 24.

**Procedure.** Set up transit over a point. Observe Polaris at $A$ or $B$, when the elongation remains constant—a 20-minute period during which Polaris appears to move vertically and actually varies not more than 0.1 minute from the elongation. Depress telescope and set a point ahead. Turn off the angle in Table 19 to give the true north.

* *L. C. Urquhart, Civil Engineering Handbook, McGraw-Hill.*

**TABLE 19: AZIMUTHS OF POLARIS AT ELONGATION, FOR THE BEGINNING OF YEARS 1940–1950 ***

(Computed by the U. S. Naval Observatory)

| Latitude | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 25 | 1 7.6 | 1 7.3 | 1 7.0 | 1 6.7 | 1 6.4 | 1 6.1 | 1 5.7 | 1 5.3 | 1 5.0 | 1 4.6 | 1 4.2 |
| 26 | 8.2 | 7.9 | 7.6 | 7.3 | 7.0 | 6.6 | 6.3 | 5.9 | 5.5 | 5.1 | 4.8 |
| 27 | 8.8 | 8.5 | 8.2 | 7.9 | 7.5 | 7.2 | 6.8 | 6.5 | 6.1 | 5.7 | 5.3 |
| 28 | 9.4 | 9.1 | 8.8 | 8.5 | 8.2 | 7.8 | 7.4 | 7.1 | 6.7 | 6.3 | 5.9 |
| 29 | 10.1 | 9.8 | 9.5 | 9.2 | 8.8 | 8.5 | 8.1 | 7.7 | 7.3 | 6.9 | 6.5 |
| 30 | 10.8 | 10.5 | 10.2 | 9.8 | 9.5 | 9.1 | 8.8 | 8.4 | 8.0 | 7.6 | 7.2 |
| 31 | 11.5 | 11.2 | 10.9 | 10.6 | 10.2 | 9.9 | 9.5 | 9.1 | 8.7 | 8.3 | 7.9 |
| 32 | 12.3 | 12.0 | 11.7 | 11.3 | 11.0 | 10.6 | 10.2 | 9.8 | 9.4 | 9.0 | 8.6 |
| 33 | 13.1 | 12.8 | 12.5 | 12.1 | 11.8 | 11.4 | 11.0 | 10.6 | 10.2 | 9.8 | 9.4 |
| 34 | 13.9 | 13.6 | 13.3 | 13.0 | 12.6 | 12.2 | 11.8 | 11.4 | 11.0 | 10.6 | 10.2 |
| 35 | 14.8 | 14.5 | 14.2 | 13.8 | 13.5 | 13.1 | 12.7 | 12.3 | 11.9 | 11.5 | 11.1 |
| 36 | 15.8 | 15.4 | 15.1 | 14.8 | 14.4 | 14.0 | 13.6 | 13.2 | 12.8 | 12.4 | 11.9 |
| 37 | 16.8 | 16.4 | 16.1 | 15.7 | 15.4 | 15.0 | 14.6 | 14.1 | 13.7 | 13.3 | 12.9 |
| 38 | 17.8 | 17.5 | 17.1 | 16.8 | 16.4 | 16.0 | 15.6 | 15.1 | 14.7 | 14.3 | 13.9 |
| 39 | 18.9 | 18.5 | 18.2 | 17.8 | 17.4 | 17.0 | 16.6 | 16.2 | 15.8 | 15.3 | 14.9 |
| 40 | 20.0 | 19.7 | 19.3 | 19.0 | 18.6 | 18.2 | 17.7 | 17.3 | 16.9 | 16.4 | 16.0 |
| 41 | 21.2 | 20.9 | 20.5 | 20.1 | 19.7 | 19.3 | 18.9 | 18.5 | 18.0 | 17.6 | 17.1 |
| 42 | 22.5 | 22.1 | 21.8 | 21.4 | 21.0 | 20.6 | 20.1 | 19.7 | 19.2 | 18.8 | 18.3 |
| 43 | 23.8 | 23.5 | 23.1 | 22.7 | 22.3 | 21.9 | 21.4 | 21.0 | 20.5 | 20.0 | 19.6 |
| 44 | 25.2 | 24.9 | 24.5 | 24.1 | 23.7 | 23.2 | 22.8 | 22.3 | 21.9 | 21.4 | 20.9 |
| 45 | 26.7 | 26.3 | 25.9 | 25.5 | 25.1 | 24.7 | 24.2 | 23.7 | 23.3 | 22.8 | 22.3 |
| 46 | 28.2 | 27.9 | 27.5 | 27.1 | 26.6 | 26.2 | 25.7 | 25.2 | 24.8 | 24.3 | 23.8 |
| 47 | 29.9 | 29.5 | 29.1 | 28.7 | 28.3 | 27.8 | 27.3 | 26.8 | 26.3 | 25.8 | 25.3 |
| 48 | 31.6 | 31.2 | 30.8 | 30.4 | 30.0 | 29.5 | 29.0 | 28.5 | 28.0 | 27.5 | 27.0 |
| 49 | 33.4 | 33.0 | 32.6 | 32.2 | 31.7 | 31.3 | 30.8 | 30.3 | 29.8 | 29.2 | 28.7 |
| 50 | 1 35.4 | 1 35.0 | 1 34.5 | 1 34.1 | 1 33.6 | 1 33.2 | 1 32.6 | 1 32.1 | 1 31.6 | 1 31.1 | 1 30.6 |

*Corrections for middle of months*

| For middle of— | Correction |
|---|---|
| | ′ |
| Jan. | −0.5 |
| Feb. | −0.4 |
| Mar. | −0.3 |
| Apr. | −0.1 |
| May | +0.1 |
| June | +0.2 |
| July | +0.2 |
| Aug. | +0.1 |
| Sept. | −0.1 |
| Oct. | −0.3 |
| Nov. | −0.6 |
| Dec. | −0.8 |

These data may be secured annually from the current *Nautical Ephemeris* or similar source.

* *From War Department, Surveying Tables.*

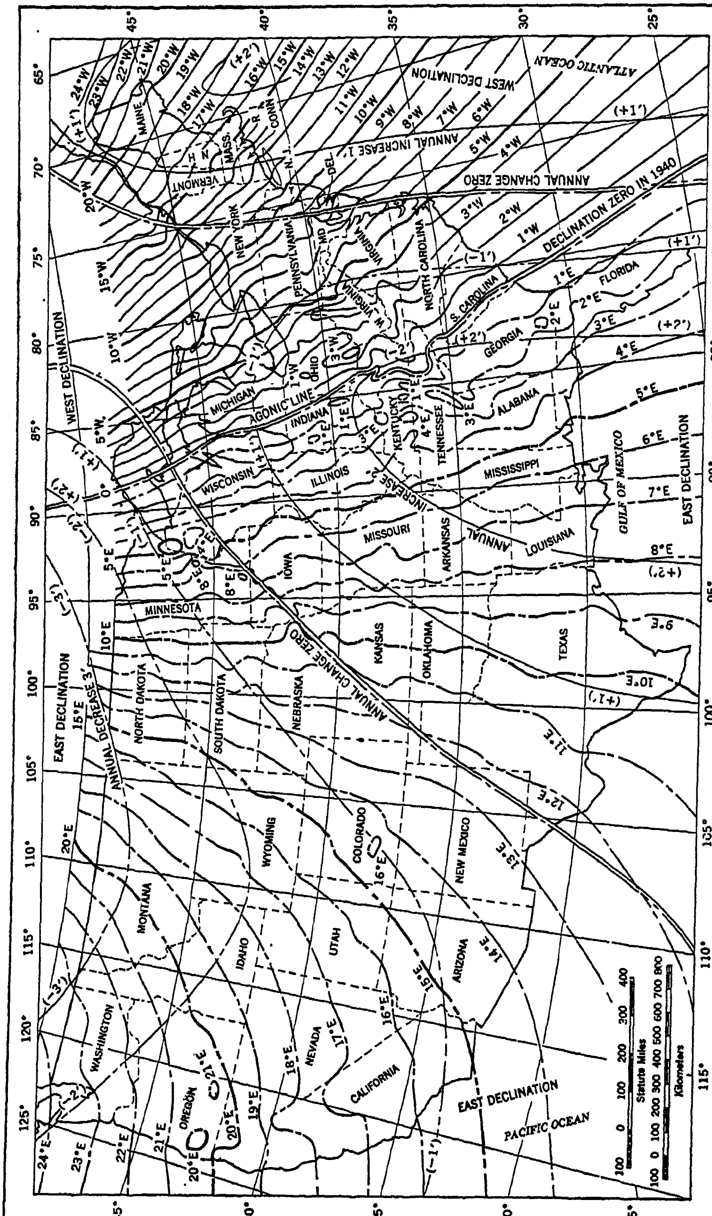
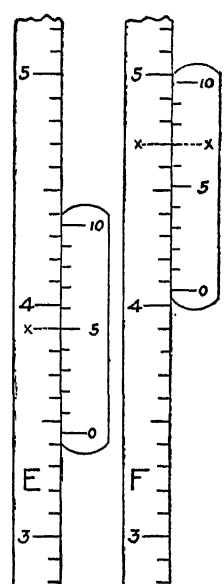



FIG. 25. Isogonic chart of the United States for 1940. *From Tracy, Plane Surveying, by permission of the author and John Wiley & Sons.*

There are two sets of lines on the isogonic chart, Fig. 25, which may be distinguished in two ways: (1) the isoporic lines are much smoother than the isogonic lines; (2) the isoporic lines are numbered in minutes and the isogonic lines in degrees.

The isogonic lines or lines of equal declination (also called "lines of equal variation of the compass") are drawn for January 1940. East of the agonic line, the lines are solid, signifying that the north end of the compass needle points west of true north; west of the agonic line they are dashed, and the compass points east of true north. The lines are drawn to show a smoothed distribution; in the more disturbed regions, the sinuosities of the lines must be regarded as an indication of irregularity rather than as a close representation of the declination.

Magnetic declination is subject to gradual change, the rate of which depends upon time and place. The annual rate of change prevailing from about 1934 to 1940 may be estimated from the isoporic lines. These lines are solid in regions where the prevailing declination was increasing, and dashed in regions in which the declination was decreasing. Note that, when an isoporic line crosses the agonic line, its sign changes.




*From Tracy, Surveying: Theory and Practice, by permission of the author and John Wiley & Sons.*

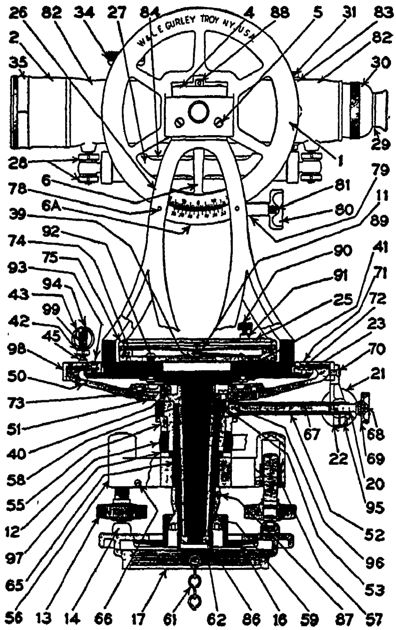
### Vernier

Accurate readings on scales will fall somewhere between rather than on the subdivision marks on a scale. The vernier is a supplementary scale designed to aid in evaluating these fractional overages.

It is an adjacent scale against which slides the main scale as illustrated in the figure at the right. The zero of the vernier scale becomes the point from which the reading on the main scale is taken. The divisions of the vernier are a little smaller than those on the main scale. Thus 10 subdivisions on the vernier scale equal 9 subdivisions on the main scale.

The refinement is given by reading to the nearest subdivision on the main scale opposite the zero on the vernier and looking along the scale until the point is reached where the subdivisions of the vernier scale and the main scale appear coincident. For instance, in the two scales illustrated, if the major subdivisions on the main scales are tenths of a foot, the reading of the scale marked *E* would be 0.345 ft. The reading of the scale marked *F* would be 0.407 ft.

# INSTRUMENTS AND THEIR ADJUSTMENTS*

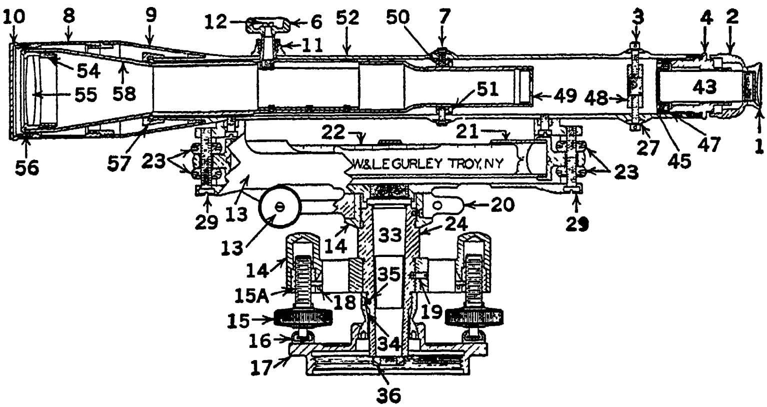


Cross section of Gurley transit.

## Parts of Gurley Precise Transits

1. Vertical circle guard.
2. Dust shield, protecting objective slide.
3. Detachable sunshade. (Not illus.)
4. Cap screws to standard.
5. Screws—guard to standard.
6. Vertical circle.
6A. Vertical circle vernier.
7. Side plate level.
9. North (or transverse) plate level.
11. Compass needle.
12. Lower (or leveling head) clamp.
13. Leveling screw.
14. Leveling screw cup.
15. Lower tangent screw. (Not illus.)
16. Shifting center.
17. Bottom plate.
18. Lower clamp screw. (Not illus.)
20. Upper (or limb) clamp screw.
21. Upper (or limb) tangent screw.
22. Upper (or plate) tangent hanger.
23. "A" vernier.
24. Needle lifter.
25. Compass glass cover in metal bezel ring.
26. One piece truss standard.
27. Telescope level.
28. Adjusting nuts for telescope level.
29. Eyepiece cap.
30. Knurled ring for eyepiece focusing.
31. Capstan screw for adjusting cross-wires.
32. Clamp screw for telescope axle.
33. Objective slide adjusting screw.
34. Objective focusing pinion.
35. Objective cap.
36. Side (or longitudinal) level vial.
39. Center pin.
40. Limb centering screws.
41. Screw—plate to spindle.
42. Capstan nut—north (or transverse) vial.
44. Spring guard to north vial.
45. Plate level post.
46. Top plate.
47. Screw—plate to standard.
49. Index pointer for magnetic declination.
50. Limb.
51. Socket.
52. Limb clamp.
53. Screw—clamp sleeve to socket.
54. Clamp sleeve.
55. Clamp collar.
56. Spider, or four-arm piece.
57. Leveling screw nut.
58. Spindle.
59. Half-ball.
61. Jack or plummet chain.
62. Bottom cap.
64. Washer—end of spindle.
65. Shell.
66. Keeper screw.
67. Limb clamp plunger.
68. Locking screw—head to stem of clamp screw.
69. Clamp screw head.
70. Screw—tangent hanger to plate.
71. Vernier glass.
72. Screw—vernier to plate.
73. Screw—limb to socket.
74. Needle circle.
75. Bezel ring.
78. Screw—v.c. vernier to standard.
79. Axis tangent screw stem.
80. Head, axis tangent screw.
81. Locking screw—head to stem of axis tangent screw.
82. Telescope.
83. Collet, for cross-wire adjusting.
84. Telescope level vial.
86. Nut—end of spindle.
87. Half-ball set screw.
88. Capstan adjusting screw in standard cap.
90. Needle lifter screw.
91. Needle lifter housing.
92. Screw—compass to plate.
93. Screw—cover ring to standard base.
94. Nut—top of plate level post.
95. Take-up screw to limb tangent
96. Gib—leveling head clamp.
97. Spacer ring.
98. Cover ring.
99. Plate level adjusting spring.

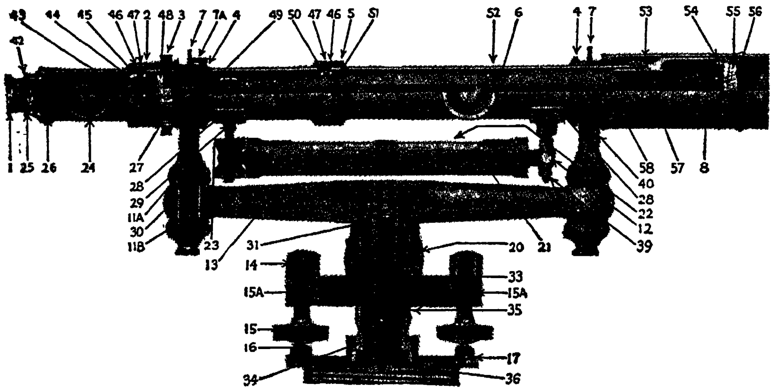
* *From Surveying Instrument Manual, W. & L. E. Gurley, Troy, N. Y.*




Cross section of Gurley dumpy level.

## Parts for Gurley Dumpy Levels

1. Eyepiece cap.
2. Eyepiece focusing ring.
3. Capstan screw for adjusting cross wires.
4. Eyepiece body.
6. Objective focusing pinion.
7. Objective slide centering screw.
8. Dust shield.
9. Main tube head.
10. Objective cap.
11. Objective pinion body.
12. Objective pinion screw.
13. Bar.
14. Leveling head.
15. Leveling screw.
15A. Leveling screw bushing.
16. Leveling screw cup.
17. Bottom plate.
18. Leveling screw keeper screw.
19. Shell set screw.
20. Leveling head clamp.
21. Telescope level.
22. Telescope level vial.
23. Capstan adjusting nuts for telescope level vial.
24. Shell or outer bearing.
27. Collet for cross-wire adjusting screws.
29. Post for adjusting telescope level.
33. Spindle.
34. Half ball.
35. Screw for half ball.
36. Nut, end of spindle.
45. Eyepiece centering ring.
47. Eyepiece centering screw.
48. Cross-wire reticule.
49. Diaphragm in slide.
50. Objective slide centering ring.
51. Babbit, slide centering ring.
52. Main tube.
54. Inner ring, objective setting.
55. Objective lens.
56. Outer ring, objective setting.
57. Babbit, for objective end.
58. Objective slide.




Quarter section of Gurley wye level.

## Parts for Gurley Wye Levels

1. Eyepiece cap.
2. Cover ring, covering eyepiece centering screws.
3. Capstan screw, for adjusting cross wires.
4. Wye rings.
5. Cover ring, covering objective slide adjusting screws.
6. Objective focusing pinion.
7. Wye pin.

7A. Wye clip stop pin.

8. Dust shield.
9. Sunshade.*

11A. Wye capstan nuts (upper).
11B. Wye capstan nuts (lower).

12. Level lateral adjusting screw.
13. Wye bar.
14. Leveling head.
15. Leveling screw.
16. Leveling screw cup.
17. Bottom plate.
20. Leveling head clamp.
21. Telescope level complete.
22. Telescope level vial.
23. Vertical adjusting capstan nuts for telescope level.
24. Eyepiece focusing pinion.
25. Sleeve for eyepiece.
26. Eye end ring.
27. Collet, for cross-wire centering screws.
28. Screws for telescope level hanger and post.
29. Telescope level post.
30. Spline.
31. Spindle head.
33. Spindle.
34. Half ball.
35. Screw for half ball.
39. Hanger for telescope level.
40. Wye complete.
42. Babbit ring, in sleeve for eyepiece.
43. Eyepiece.
44. Babbit, in eyepiece centering ring.
45. Eyepiece centering ring.
46. Collet, for eyepiece centering screw.
47. Eyepiece centering screw.
48. Cross-wire reticule.
49. Diaphragm in slide.
50. Slide centering ring.
51. Babbit, slide centering ring.
52. Main tube.
53. Binding ring.
54. Inner ring, objective setting.
55. Objective lens.
56. Outer ring, objective setting.
57. Babbit, for objective end.
58. Objective slide.
59. Objective cap.*

* Not illustrated.

## Hints on Adjustments

Before proceeding with any adjustment, read the following suggestions carefully.

**Making the Adjustments.** Do not attempt to perfect each adjustment the first time as succeeding adjustments may disturb those already made. It is better to keep repeating the entire series until a final check shows each adjustment to be perfect.

**Inspection of Instrument.** Before adjusting any instrument, clean it thoroughly. Dirt in bearings will not permit a true adjustment. If adjusting screws or nuts are dirty they will not hold adjustment very long. Damaged or worn screws should be replaced by new factory parts as soon as possible. Damaged or worn bearings or damaged structural parts should be repaired and refitted at the factory. Clamps, tangent screws, and tangent springs should be clean and the clamp arm should be examined to make sure there is no indentation where the tangent screw presses. Be sure that the instrument is correctly assembled and that the holding screws are set up solidly but not overstrained. The telescope should be clean, the lenses showing objects sharply and without astigmatism. Be sure that the object lens is tight in its setting and that the setting is screwed tightly in its tube. All axis bearing caps should be screwed up to the proper tension. The proper fit of the telescope axle and the elimination of "walk" is very important. Check the level vials to see that they are firm in their cases. Examine the shoes on the tripod to make sure they are tight.

**Select a Suitable Location.** Established offices should provide a substantial pier or wall bracket wherewith to support the instrument when adjusting. Targets and scales should be set at convenient distances and elevations. In a limited space, particularly indoors, telescopes focused at infinity should be set up for use as collimators. On construction work an adjusting site should be selected, targets erected and a stake driven to define the instrument position if a tripod and not a permanent support is used. In selecting such sites, avoid places where the line of sight would pass over a railroad track or paved highway, near a heated building, or through successive areas of light and shadow. Protect the instrument from wind and direct rays of the sun, particularly when they strike only one side of the instrument at a time.

**Setting up the Instrument.** Select a spot where the ground is firm and dry so that moving around the instrument will not disturb it. If the instrument is set on a floor of concrete, brick or stone, make sure that there are no loose sections. Chip holes in a smooth floor to prevent the tripod points from slipping. After screwing the instrument to the tripod, loosen the tripod bolts, then tighten them, in order to remove all residual torque in the tripod head. This helps hold the transit on line. Tighten the leveling screws firmly, but do not force them.

## Transits

The adjustments of transits are as follows:

1. Parallax.
2. Rectify cross wires.
3. Collimation at distant focus.
4. Collimation at minimum focus.
5. Telescope axis.
6. Telescope level.
7. Plate levels.
8. Vertical circle vernier.
9. Center eyepiece.
10. Balance compass needle.
11. Straighten needle
12. Center pivot.

### Description of Transit

The transit, as generally constructed today, serves to measure angles in azimuth and in altitude. It, therefore, consists of two divided circles or limbs, one of which rotates about a vertical axis and the other about a horizontal axis. Each graduated surface is made perpendicular to its axis of rotation. The pointer of the instrument is a telescope, supported by standards and plate, the plate carrying the indices or verniers. The spindle, carrying the plate and standards, and the socket, carrying the horizontal limb, constitute the "centers" which rotate about each other and within the bearing of the leveling head.

The "centers" or vertical axis is made plumb by two spirit levels mounted on the plate. These levels are adjustable, and they can be readily checked by reversal about the centers.

The telescope is mounted with an axle which rides in bearings on top of the standards. For the axle to form a horizontal axis it must be at right angles to the vertical axis, and adjustment is provided for raising or lowering one end of the axle.

The pointer of the telescope is an optical line of sight passing through the optical center of the objective lens and the intersection of the cross wires. This is commonly called the line of collimation. The cross-wire ring is made adjustable so that the line of collimation can be adjusted at right angles to the horizontal axis or telescope axle.

In order to provide a datum for altitude angles, a spirit level is attached to the telescope so that its axis can be adjusted parallel to the line of collimation.

A clear understanding of the relationship between the various axes of a transit is helpful in performing adjustments. Those outlined can be performed by the instrument man; detailed instructions are given on succeeding pages. Errors of eccentricity should be corrected at the factory. Errors of parallax are due to improper manipulation.

**1. Parallax.** *Parallax is eliminated by correct focusing of the objective lens on the cross wires.*

*Owing to differences in eyesight among individual users, it is necessary also to focus the eyepiece on the cross wires. Strictly speaking, this is not an adjustment but rather a manipulation that should be performed each time an accurate pointing is desired. Since incorrect focusing will affect other adjustments involving the use of the telescope, it is listed herein as the first adjustment, and it is important that every detail be followed carefully.*

(*a*) Sight through telescope and make preliminary focus of eyepiece on cross wires. Turn knurled ring at eye end of telescope, until wires appear black and sharp. (On some transits turn eyepiece cap or possibly an eyepiece pinion on side of telescope.)

*Eye should be relaxed and time of setting should be brief, otherwise the eye may accommodate itself to the telescope rather than the telescope become adjusted to the eye. If both eyes can be left open, a better focus will be obtained.*

(*b*) Focus the objective lens on a clearly defined, well-lighted target about 300 ft. away. Turn the objective focusing pinion slowly backward and forward of the position of focus, at the same time wagging the head. Observe for apparent lateral movement between target image and cross wires. Stop focusing at the point where no lateral displacement appears. Disregard sharpness of image and of cross wires. It is this objective focusing which is important in the elimination of parallax.

(*c*) If necessary to sharpen the image, refocus the eyepiece slightly. It will be found that the cross wires also will be more distinct.

(*d*) Further focusing of the eyepiece will not be necessary unless the eye tires or a different observer uses the instrument, in which event paragraphs *b* and *c* should be repeated.

(*e*) On surveys of a high order, paragraph *b* should be followed on all pointings if the observer wishes surely to eliminate parallax error due to focusing.

*It may be pointed out that a young man has more trouble than an old man in getting an eyepiece properly focused. This is due to the greater "accommodation" of the younger eye. The above procedure tends to produce a relaxed and normal condition of the eye when setting the final focus of the eyepiece. Furthermore, greater difficulty is experienced with low magnification and with the simple eyepiece of the inverting telescope.*

**2. Rectify Cross Wires.** *To make the vertical cross wire perpendicular to the telescope axis.*

(*a*) Sight through telescope and set one end of the vertical cross wire on a sharply defined point *A*, Fig. 26.

(*b*) Elevate or depress telescope so that vertical wire traces over point. If wire coincides with point throughout its length, its position is correct.

(*c*) If not, slightly loosen all four capstan screws, located on eyepiece end of telescope.

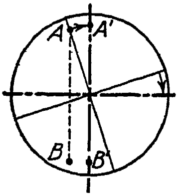


FIG. 26.

(d) Move cross-wire ring around, in proper direction, until test shows that vertical wire exactly traces point. Hold screw driver against each of the collets and tap lightly against it.

(e) Tighten capstan screws and check.

**3. Collimation at Distant Focus.** *To make the collimation plane of the vertical cross wire perpendicular to the telescope axis.*

(a) Set up and sight vertical wire on a sharply defined point $A$ (see Fig. 27), 200 or 300 ft. away.

(b) Transit the telescope and set a point $B$ at approximately the same elevation and distance as $A$.

(c) Leave the telescope reversed, rotate the transit plate a half turn, and again sight on $A$.

(d) Again transit the telescope (bring it to its normal position), and set point $C$.

(e) Mark a new point $E$, one-quarter the distance from $C$ to $B$.

(f) By turning the horizontal capstan screws shift the vertical cross wire until it is set on point $E$.

(g) Again set on $A$ and repeat until instrument will make both points, $B$ and $C$, coincide at $D$.

(h) Check rectification of vertical wire (refer to section 2).

**4. Collimation at Minimum Focus.** *In most Gurley transits the objective slide rear bearing is adjustable, so that the slide can be made to move parallel to the line of collimation and make it accurate for sighting at all distances. This adjustment is carefully made in the factory and, barring accident to the transit, should require no changing. With Gurley transits having inner-slide focusing any correction necessary can be made in the field; others should be returned to their makers. With internal focusing telescopes this construction is not permitted.*

(a) Set up and sight vertical wire on a sharply defined point, 200 or 300 ft. away.

(b) Place a horizontal scale or rod about 6 ft. in front of telescope (not nearer than point of minimum clear focus), and so that it appears just under the horizontal cross wire in the field of view, without moving the telescope.

(c) Focus on scale and read vertical wire intersection.

(d) Turn transit plate a half turn, transit telescope, and again set vertical wire on distant point.

(e) Without moving telescope, focus on nearby scale and read vertical wire intersection.

(*f*) If second reading (*e*) coincides with first reading (*c*), the objective slide is in adjustment with the vertical wire.

(*g*) Turn nearby scale or rod to vertical position in field of view and repeat readings using horizontal wire intersection. If two readings coincide, the objective slide is parallel to the horizontal wire.

(*h*) If not, correct for half the error by moving the rear bearing ring of the objective slide up or down or to the right or left as required. Turn slotted screws near or in telescope axis, using screw driver. Turning screw clockwise draws ring towards screw. Loosen opposite screw first. With an erecting telescope, actual movement should be opposite to apparent movement. With many telescopes, screws are on a 45° angle with respect to the cross wires; hence they are to be turned in pairs in order to move the bearing ring as required.

(*i*) Repeat sections 3 and 4 until the conditions of both are satisfied.

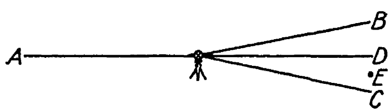



FIG. 27.

**5. Telescope Axis.** *To make the telescope axis perpendicular to the vertical axis or spindle.*

(*a*) Set up transit.

(*b*) Sight on a high point *A* (see Fig. 28).

(*c*) Depress telescope and set point *B* on ground, in front of instrument.

(*d*) Rotate instrument 180° and transit telescope.

(*e*) With telescope in reversed position, again sight on point *B*.

(*f*) Elevate telescope and note point *C*.

(*g*) Note a new point *D* halfway between *B* and *C*.

(*h*) Raise or lower the right end of the telescope axle until the vertical cross wire intersects the halfway point *D*, when elevating telescope from point *B*.

To raise or lower the telescope axle turn the right-hand threaded capstan headed screw which is to be found under the standard cap on the right-hand side. Turn clockwise to raise, counterclockwise to lower.

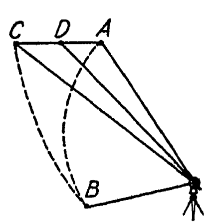



FIG. 28.

Before raising:

*On old-model Gurley Transits:* Loosen cap screws.

*On late-model Gurley Transits:* Loosen capstan screw on top of standard.

After adjusting:

*On old-model Gurley Transits:* Tighten the two cap screws equally until there is sufficient friction on the axle bearing to keep the telescope end from dropping under its own weight. On some models, laminated shims have been placed under the standard cap. In such cases the cap screws should be set up solidly. If the telescope transits too freely, remove laminations from the shims until the proper braking action is arrived at. Check and adjust the cap screws on the left-hand standard so that these provide equal braking power on both ends of telescope axle.

*On late-model Gurley Transits:* Tighten the two capstan screws on top of standards. Adjust both screws equally until there is sufficient braking action on the axle to keep the telescope end from dropping. Check and adjust the capstan screws on the left-hand standard so that they provide equal braking power on both ends of telescope axle.

(*i*) Check and repeat until transit will make points $A$ and $C$ coincide.

**6. Telescope Level.** *To make the axis of the bubble parallel to the line of sight when the latter is horizontal.*

*The "Four Peg" Method*

*For the "Two Peg" method, see p. 274*

(*a*) Drive four stakes, $A$, $B$, $C$, and $D$, in line and exactly equidistant, from 50 to 100 ft. apart (see Fig. 29).

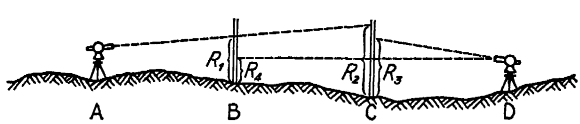



FIG. 29.

(*b*) Set up the transit at $A$.

(*c*) Bring the bubble to the center of the telescope level.

(*d*) Read the elevation of the line of sight on a rod held at both $B$ and $C$, calling the first reading $R_1$ and the second $R_2$.

(*e*) Set up the transit at $D$.

(*f*) With the bubble in the center of the telescope level, read the rod on $C$, calling it $R_3$.

(*g*) Add $R_1$ to $R_3$, subtract $R_2$, and set target on rod to this result.

$$R_4 = (R_1 + R_3 - R_2)$$

(*h*) Hold rod on *B*.

(*i*) By means of the axis tangent motion, incline the telescope until the horizontal wire intersects the target.

(*j*) Raise or lower one end of the bubble tube, by turning the capstan nuts, until the bubble returns to the center.

*Reversion Vial: A procedure simpler than the peg method can be employed if the telescope level vial is of the reversion type.*

(*a*) Set up transit, sight on level rod about 100 ft. distant, and center bubble.

(*b*) Read level rod (middle horizontal wire).

(*c*) Rotate instrument 180° in azimuth, transit telescope, again sight on rod, and center bubble.

(*d*) Read level rod.

(*e*) Average readings *b* and *d*. Set horizontal wire to average reading on rod. Center bubble by capstan adjusting nuts.

**7. Plate Levels.** *To make the bubble tube axes perpendicular to the vertical axis or spindle.*

(*a*) Set up transit on tripod.

(*b*) Rotate transit plate so that each bubble is in line with a pair of opposite leveling screws.

(*c*) Bring plate level bubbles to the center in both tubes.

(*d*) Turn the plate through 180° in azimuth.

(*e*) Note the amount that the bubbles move from the center.

(*f*) Raise or lower one end of each bubble tube as required to bring the bubbles back one half the amount they moved off.

*To raise or lower one end of the bubble tube:* On transits having capstan nuts above and below level tube, use adjusting pin to raise or lower both nuts as required. Do not force together so as to spring bubble tube.

On transits having a slotted screw at top of adjusting post, use adjusting pin to raise or lower only the capstan nut, underneath the tube. Coiled spring inside tube supplies proper tension. Adjust end of tube which will keep slotted screw about flush with top of tube.

(*g*) Level up and repeat the above until both bubbles remain in the center when rotating them 180°. *Check and correct the bubbles alternately.*

**8. Vertical Circle Vernier.** *To make the vertical circle (or arc) read zero when the line of collimation is horizontal.*

(*a*) Level up transit carefully, using telescope level.

(*b*) Center bubble of telescope level, using axis tangent motion. Check bubble adjustment, section 6.

(*c*) Inspect vernier and vertical circle to see if zeros of each coincide.

(*d*) If not, slightly loosen screws which hold vernier to standard.

(*e*) Shift vernier until zeros coincide.

(*f*) Tighten vernier screws and check.

*Two-Vernier Vertical Circle. To make the vertical circle read zero when the line of collimation is horizontal.*

(*a*) Level up transit carefully, using telescope level.

(*b*) Center bubble of telescope level, using axis tangent motion.

(*c*) Turn capstan headed screw until zeros of one vernier and vertical circle coincide.

*To make zeros of verniers read 180° apart.*

(*a*) Make line of collimation horizontal and also one vernier read zero as described above.

(*b*) If opposite vernier does not read zero, slightly loosen the screws which hold that vernier to the vernier frame.

(*c*) Shift vernier until zeros coincide.

(*d*) Adjust spacing between vernier and circle until end graduations on vernier match with limb.

(*e*) Tighten vernier screws and check.

*Beaman Stadia Arc Indices. To make indices read zero when vernier reads zero.*

(*a*) Set vernier to read zero on limb.

(*b*) If indices $H$ and $V$ do not read zero, slightly loosen index screws.

(*c*) Shift indices until they both read zero.

(*d*) Tighten index screws.

**9. Center Eyepiece.** *To make the cross wires appear in the center of the field of view. This adjustment is not an essential to accuracy but is of convenience to the observer.*

(*a*) After the cross wires have been adjusted, observe whether they appear in the center of the field.

(*b*) If not, unscrew the entire eyepiece from the telescope, turning raised rim ahead of knurled ring.

(*c*) Move the eyepiece slide in proper direction (opposite to apparent direction) by means of opposing flat headed screws in eyepiece. Estimate the amount of movement necessary.

(*d*) Replace the eyepiece in telescope and, if necessary, repeat until the eyepiece is properly centered.

**10. Balance Compass Needle.** *The compass needle is balanced horizontally, as near as possible, for the locality to which it is sent. The metal spring or bright coiled wire on the south end of the needle slides along the needle to enable the instrument man to do exact balancing in the field. The needle should be tested for balance when the instrument is moved from one locality to another. Balancing at the office, particularly in a large building, will probably not give satisfactory results.*

(*a*) Level up the instrument.

(*b*) Release the needle on its pivot.

(*c*) Remove the compass glass by pressing the palm of the hand flat on the glass and turning counterclockwise.

*Some transits have a set screw in the bezel ring, which should be removed before turning ring. This is located in either the NW or SE quadrants. If glass is tight, tap around bezel ring with handle of screw driver to loosen threads. The compass glass cannot be removed from between the standards on some Gurley transits without first detaching the vertical axis tangent bar which is held to the standard by two screws. However, it is unnecessary to remove the compass glass entirely when making adjustments.*

(*d*) Note the dip of the needle, raise one side of the compass glass, and carefully remove the needle. Slide the counterbalance along the needle toward the high end.

(*e*) Lower the needle on its pivot point as gently as possible.

(*f*) Repeat until the needle balances.

(*g*) Replace the compass glass, taking care not to cross the threads. Finish turning with index pointer at *N* position. Replace locating set screw.

(*h*) Raise the needle from its pivot until ready to use.

**11. Straighten Needle.** *To make both ends of the needle read 180° apart in one position. This makes both ends and the center of the needle lie in the same vertical plane.*

(*a*) Set up compass, lower needle gently on the center pin, and remove the cover glass.

(*b*) With a small splinter of wood, bring the north end of the needle exactly opposite the north zero mark of the circle.

(*c*) Read the south end of the needle.

(*d*) Rotate the needle a half turn and bring the south end exactly opposite the north zero.

(*e*) Read the north end of the needle.

(*f*) If the two readings agree (paragraphs *c* and *e*) the needle is straight.

(*g*) If not, correct for half the error by bending the needle.

(*h*) Repeat the test until the needle is straight.

**12. Center Pivot.** *To make both ends of the needle read 180° apart in all positions. This brings the pivot point exactly in the center of the compass circle.*

(*a*) After straightening needle, bring north end of needle exactly opposite the north zero mark of the circle.

(*b*) Note whether south end of needle reads zero.

(*c*) If not, correct for the whole error by bending the center pin in a direction at right angles to the needle. *Use wrench, carried in spare parts kit, to bend center pin.*

(*d*) Rotate the needle a quarter turn, bring the north end opposite a 90° mark, and note whether the south end of the needle reads 90°.

(*e*) If not, correct for the whole error by bending the center pin in a direction at right angles to the needle.

(*f*) Repeat the above, reading first at the zero and then at the 90° marks, until both ends of the needle read alike in both positions.

### Adjustments of Wye Levels

The adjustments of Gurley wye levels are as follows:

1. Parallax.
2. Rectify cross wires.
3. Collimation at distant focus.
4. Collimation at minimum focus.
5. Telescope level vial.
6. Wyes.
7. Center eyepiece.

### Adjustments of Dumpy Levels

The adjustments of Gurley dumpy levels are as follows:

1. Parallax.
2. Telescope level vial.
3. Rectify cross wires.
4. Collimation at distant focus.
5. Collimation at minimum focus.
6. Center eyepiece.

A level is an instrument used to determine the position of all points in a horizontal plane. It consists of a collimated line of sight adjusted parallel to the axis of a spirit bubble. This fundamental description should be kept in mind when adjusting and using a level of any type.

The type of level is determined from the structural arrangement of the parts necessary to adjust the axis of the bubble parallel to the line of sight and the convenience of keeping the bubble centered when taking a reading.

With the wye level, the telescope is provided with two accurately machined bearing rings, truly circular and of equal diameter, separated by about half the length of the telescope. These rest in wye bearings which are adjustable in the wye bar, which is permanently fixed at right angles to the vertical spindle. Two level posts attached to the telescope (usually underneath) carry the level vial, the position being fixed by adjusting nuts, usually at both ends.

With the dumpy level, the telescope, bar, and spindle are assembled as one unit, the workmanship being such that the axis of the telescope is closely perpendicular to the vertical axis of rotation or spindle. Level posts may be attached either to the bar or to the telescope, these carrying the level vial with adjusting nuts at both ends.

This difference in construction between the wye and dumpy level determines a difference in adjustment procedure. Thus, with the wye level, the collimated line of sight is made concentric with the wye rings by rotating the telescope in the wyes and adjusting the reticule carrying the cross wires. By reversing the telescope rings end for end in the wye bearings, and by adjusting the level vial in the level posts until the bubble

holds its central position in both positions of the telescope, the bubble axis is made parallel with the wye rings and thereby parallel with the collimated line of sight. As long as this parallelism holds, it is possible to do accurate leveling with a wye level, provided the level bubble is made central by the leveling screws each time a reading is taken. For convenience in keeping the bubble centered when pointing the telescope in a new direction, the wye adjustment is provided, which, by reversing the telescope about its spindle and by adjusting the wye nuts, makes the bubble axis, also the collimated line of sight, perpendicular to the spindle, or axis of rotation. When making the latter adjustment, the telescope slide should be moved by the focusing screw until the objective end of the telescope balances the eyepiece end. This position of the slide should be noted and the slide brought back to it when subsequently leveling up the instrument. Any movement of the slide from this position changes the balance of the instrument and may cause the bubble to run. This condition does not indicate a change in adjustment, since nothing has been done to change the parallelism between the bubble axis and the collimated line of sight. Therefore such a run of the bubble should be corrected by the leveling screws.

In adjusting the dumpy level, the construction necessitates a different procedure. The level bubble axis is first made perpendicular to the spindle or axis of rotation by reversing the telescope end for end about the spindle, centering the bubble by the level post adjusting nut. The collimated line of sight is then brought parallel to the bubble axis by the peg method of adjustment, the details of which are given on p. 274. For careful adjustment the objective slide should be at the position of balance, and any subsequent run of the bubble should be compensated for by the leveling screws, as explained under the wye level paragraph above.

When using a level, the adjustment or parallelism between bubble axis and collimated line of sight is important but it is equally important to make sure that the bubble is centered each time a reading is taken. To assist in this purpose, various devices from a simple mirror to a complicated prism system are used to enable the observer to see the position of the bubble at the time he reads on the rod.

The tilting type of level has been devised to assist the observer in keeping the bubble centered without recourse to the leveling screws. In addition to the change in balance caused by focusing on rods at different distances, there are other factors which cause a bubble to run without disturbing the fundamental parallelism between bubble axis and line of sight, especially so if a sensitive bubble is used.

The tilting level (used for precise leveling) has a double bar, one part attached parallel to the telescope, the other part at right angles to the spindle. The two bars are arranged to pivot one on the other, being separated by a slow-motion screw with opposing spring. A circular or bull's-

eye level on the bar or leveling head serves to plumb the spindle. Final leveling with each reading is done by centering the bubble by the slow-motion screw. Such levels are generally provided with a reflecting device so that both bubble and rod image are visible at the same time.

Tilting levels may be either of the dumpy or of the wye type. In the dumpy type, the parallelism between the bubble axis is established by the peg method of adjustment. In the wye type, the telescope is made with wye rings and with a reversion type of level attached to the side. The advantage of the wye or reversible type of tilting level is the ease of adjusting the line of collimation and the level bubble.

The relative advantages of the wye and dumpy levels boil down to a matter of individual preference. The dumpy level with fewer parts is supposed to remain in adjustment over a longer period of time. However, its adjustment is dependent upon a well-fitted spindle and socket.

The advantage claimed for the wye level is that the adjustments can be checked readily by one person (the dumpy level requires the assistance of a rodman in making the peg adjustment). The principal objection is that the adjustments are dependent upon the wye bearing rings being truly circular and equal in diameter. Since the rings are exposed to wear and to possible damage, some engineers feel that they cannot be sure of the adjustment unless the peg method is used anyway.

For construction engineering the compact solidarity of either the wye or the dumpy level gives these types the preference. However, for accuracy and speed on long lines of differential levels the tilting type is superior.

**1. Parallax.** *See parallax adjustment for transit, p. 261.*

**2. Rectify Cross Wires.** *To make the horizontal cross wire perpendicular to the vertical axis or spindle. The vertical wire is set perpendicular to the horizontal wire by the maker.*

(*a*) Set up a level on tripod. Set one end of horizontal wire on a sharply defined point *A*, Fig. 30.

(*b*) Turn level slowly about its spindle, so that horizontal wire traces over the point. Wire should coincide with point throughout its length.

(*c*) If point appears to trace dotted line *AB*, Fig. 30, slightly release pressure on capstan screws. Turn all four capstan screws only slightly and by equal amounts.

(*d*) Gently tap capstan screws in direction to close angle between horizontal wire and dotted line *AB*, Fig. 30. Rotate cross-wire ring (test, paragraph *b* above) until horizontal wire exactly traces point from *A′* to *B′*, Fig. 30.

(*e*) Tighten capstan screws (all four equally), and check.

**3. Collimation at Distant Focus.** *To make the line of sight (collimation) pass through the axis of the wye rings.*

(*a*) Set up level on tripod, remove wye pins from clips, and raise clips so that telescope is free to rotate.

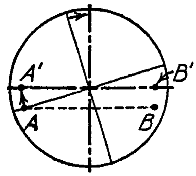



FIG. 30.

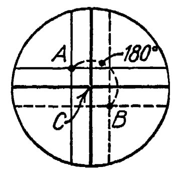



FIG. 31.

(*b*) Set intersection of cross wires on a well-defined point (*A*, Fig. 31), about 300 ft. distant.

(*c*) Carefully rotate the telescope halfway around in its wyes, and note whether the intersection of the cross wires still covers the point.

(*d*) If not, move the telescope by leveling and tangent screws until the error seems to be one-half corrected.

(*e*) Move the cross-wire ring, using each pair of opposite capstan screws successively, until the error is entirely corrected and the cross-wire intersection now covers the point (*C*, Fig. 31).

(*f*) Repeat the rectification (2) and collimation (3) of the cross wires until both adjustments are correct.

**4. Collimation at Minimum Focus.** *To make the objective slide move parallel to the line of collimation when racked in or out for focusing on distant or near targets.*

*This adjustment may be checked on any telescope but can be corrected only on Gurley inner-slide focusing telescopes. It is not on internal focusing telescopes or on the external focusing telescopes of other makes. It is primarily a factory adjustment and, barring accident, should need no correction in the field.*

(*a*) Set up level on tripod, remove wye pins from clips, and raise clips so that telescope is free to rotate.

(*b*) Check adjustment of the line of collimation (3) for a remote target.

(*c*) Unscrew the cover ring in center of telescope, exposing the flat-headed screws for adjusting the rear bearing of the objective slide.

(*d*) Set intersection of cross wires on a well-defined point about 15 ft. distant.

(*e*) Carefully rotate telescope halfway round in its wyes, and note whether the intersection of the cross wires still covers the point.

(*f*) If not, move the telescope by leveling and tangent screws until the error seems to be one-half corrected.

(*g*) Correct the remainder of the error by turning the flat-headed screws with a screw driver until the cross wires intersect on the point. Adjust first one pair of screws and then the other. Loosen one screw and tighten the other.

(*h*) Repeat sections 3 and 4 until the conditions of both are satisfied.

(*i*) Replace cover ring.

**5. Telescope Level Vial.** *To make the axis of the bubble parallel to and in the same vertical plane with the axis of the wye rings. As long as this adjustment and section 3 are correct, accurate leveling can be done with the instrument.*

(*a*) Hold level sideways with spindle horizontal, and turn focusing screw until level balances. Then set up on tripod, clamp telescope over two diagonally opposite leveling screws.

(*b*) Remove wye pins and raise wye clips.

(*c*) Bring bubble to center of tube (see Fig. 32).

(*d*) Lift telescope out of wyes, turn end for end, and replace in wyes. Note whether bubble remains in center of tube (see Fig. 33).

(*e*) If not, bring bubble halfway back to center by the leveling screws.

(*f*) Correct balance of error by turning the capstan nuts at eyepiece end of bubble tube until bubble returns to center (see Fig. 34).

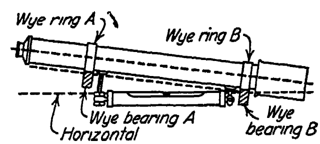



FIG. 32.

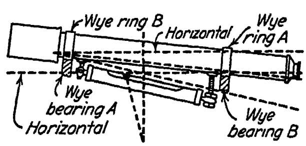



FIG. 33.

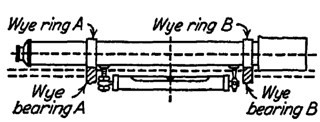



FIG. 34.

(*g*) Rotate telescope in its wyes, about 30° either side of the vertical, and note whether bubble remains in center of tube.

(*h*) If not, bring bubble all the way back to center by turning the lateral capstan screws on each side of the bubble tube post at the objective end of the level.

(*i*) Repeat the vertical adjustment, as given under section 5, paragraphs *c*, *d*, *e*, and *f* above.

(*j*) Check alternately until both the lateral adjustment and the vertical adjustment of the vial are correct.

*Note: Bubble will run if balance is changed, by running objective slide in or out. This does not indicate adjustment is out. See p. 269.*

**6. Wyes.** *To make the axis of the wyes perpendicular to the vertical axis or spindle.*

*This adjustment is made as a convenience, rather than as a necessity. Accurate leveling can be done if the bubble is in adjustment, and is centered by the leveling screws before each rod reading.*

(*a*) Set up level, rotate about spindle until telescope is over two diagonally opposite leveling screws, and bring bubble to the center of tube (see Fig. 35). Check telescope bubble adjustment, section 5, very carefully. Telescope slide must be in position of balance.

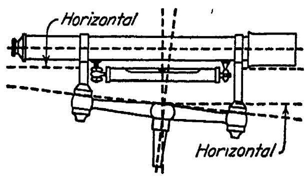



FIG. 35.

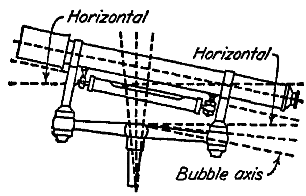



FIG. 36.

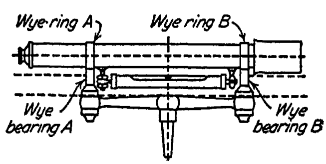



FIG. 37.

(*b*) Rotate level about spindle 180°, and note whether bubble remains in center of tube (see Fig. 36).

(*c*) If not, bring bubble halfway back to the center by the leveling screws. Raise or lower one end of the wye bar, until the bubble returns to the center, by turning a pair of capstan nuts at either end of the wye bar.

(*d*) Repeat until the bubble remains in center of tube when rotated about spindle (see Fig. 37).

**7. Center Eyepiece.** *To make cross wires appear in center of field.*

*This is not essential to the accuracy of the work, but it is a convenience to the observer to have the cross wires appear in the center of the field.*

(*a*) Set up level, and observe whether cross wires appear in center of field.

(*b*) If not, unscrew cover ring between cross wires and eye end of telescope.

(*c*) Turn the flat-headed screws with a screw driver until the cross wires appear in the center of the field.

*Adjust first one pair of screws, and then the other. Loosen one screw and tighten the opposite one. Correct in a direction opposite to the apparent error.*

(*d*) Replace cover ring.

**Adjustments of Dumpy Levels**

**1. Parallax.** *See parallax adjustment for transit, p. 261.*

**2. Telescope Level Vial.** *To make the axis of the bubble perpendicular to the vertical axis or spindle.*

(*a*) Set up level on tripod, rotate about spindle until telescope is over two diagonally opposite leveling screws, and bring bubble to center of tube.

(*b*) Rotate level about spindle 180°, and note whether bubble remains in center of tube.

(*c*) If not, bring the bubble halfway back to the center by the leveling screws.

(*d*) Correct balance of error by turning capstan nuts at either end of bubble tube, until bubble returns to center.

(*e*) Alternate over both pairs of leveling screws until the bubble remains in center of tube when rotated about spindle.

**3. Rectify Cross Wires.** *To make the horizontal cross wire perpendicular to the vertical axis or spindle. Vertical wires are set by the maker at right angles to the horizontal wire.*

(*a*) Set up level on tripod, and set one end of horizontal cross wire on a sharply defined point (*A*, Fig. 30).

(*b*) Turn level slowly about its spindle, so that horizontal wire traces over the point. If wire coincides with point throughout its length, its position is correct.

(*c*) If not, slightly loosen all four capstan screws located on eyepiece end of telescope.

(*d*) Move cross-wire ring around, in proper direction, until test shows that horizontal wire exactly traces point (*A′ B′*, Fig. 30).

(*e*) Tighten capstan screws and check.

**4. Collimation at Distant Focus.** *To make the line of sight parallel to the axis of the bubble.*

*The "Two Peg" Method*

*For the "Four Peg" method, see p. 264.*

(*a*) Set up level at some convenient point *A*, Fig. 38, holding rod at *C*, distant at least 100 ft. With instrument carefully leveled and bubble in center of telescope level, read rod on *C*, calling the reading $R_c$.

(*b*) Locate point *B* directly behind instrument and so that distance *AB* equals *AC*.

(*c*) Point telescope toward *B*, bring bubble to center of telescope tube, and take rod reading $R_b$.

(*d*) Set up level beside point $B$, so that eyepiece of telescope is directly over point. Level up carefully, bringing bubble to center of telescope tube.

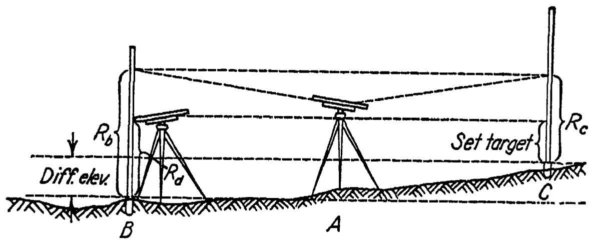



FIG. 38.

(*e*) Point eyepiece of telescope toward rod at $B$, and read through objective end of telescope, calling this reading $R_d$. If more convenient, measure along the outside center line of telescope.

(*f*) Add to $R_d$ the difference between the first readings ($R_c - R_b$).

(*g*) Set rod target to this result, and hold the rod on point $C$.

(*h*) Move the cross-wire ring up or down until the horizontal wire cuts the target, by turning the vertical pair of opposite capstan screws.

(*i*) Check by again reading rod on $B$, computing rod reading for $C$, and observing whether horizontal wire cuts the target.

**5. Collimation at Minimum Focus.** *To make the objective slide move parallel to the line of collimation when racked in or out for focusing on distant or near targets.*

*This adjustment may be checked on any telescope but can be corrected only on Gurley inner-slide focusing telescopes. It is not on internal focusing telescopes or on the external focusing telescopes of other makes. It is primarily a factory adjustment and, barring accident, should need no correction in the field.*

(*a*) After doing section 4, set up level about 15 ft. from $B$ (Fig. 38) toward $C$, which is the same distance away.

(*b*) On old-model Gurley dumpy levels unscrew the cover ring in center of telescope, exposing the flat-headed screws for adjusting the rear bearing of the objective slide.

(*c*) Level carefully and read rod $C$.

(*d*) Rotate level and focus on rod $B$. Moving objective slide out will probably cause the bubble to run, owing to the change in balance. Bring the bubble to the center by turning the leveling screws.

(*e*) Set target on rod $B$ to proper reading to give true difference in elevation ($R_c - R_b$) as determined in section 4. Cross wires should bisect target at this setting.

(*f*) If not, turn the flat-headed screws, moving the rear bearing up or down, until the horizontal wire cuts the target.

(*g*) Check sections 4 and 5 alternately, until both are correct.

**6. Center Eyepiece.** *To make the cross wires appear in the center of the field of view. This adjustment is not an essential to accuracy but is of convenience to the observer.*

(*a*) After the cross wires have been adjusted, observe whether they appear in the center of the field.

(*b*) If not, unscrew the entire eyepiece from the telescope, turning raised rim ahead of knurled ring.

(*c*) Move the eyepiece slide in proper direction (opposite to apparent direction) by means of opposing flat-headed screws in eyepiece. Estimate the amount of movement necessary.

(*d*) Replace the eyepiece in telescope, and, if necessary, repeat until the eyepiece is properly centered.

## Taping

### Changes in Temperature

Correction in feet $= C \times L(T - T_s)$.

$C = 0.0000065$ for steel tape.

$C = 0.00000056$ for invar. tape.

$L =$ length of tape in feet.

$T =$ temperature in degrees Fahrenheit at which tape is used.

$T_s =$ temperature at which tape was standardized (62° F. or 68° F.).

### Variation in Tension

Correction in feet $= \dfrac{(P - P_s)L}{AE}$.

$P =$ tension applied.

$P_s =$ standard tension (10 to 15 lb.).

$L =$ length of tape in feet.

$A =$ cross section area of tape in square inches (light steel tape $=$ 0.0025 $\pm$; heavy steel tape $= 0.01\pm$).

$E =$ modulus of elasticity in pounds per square inch (30,000,000 for steel tapes).

### Sag

Correction in feet between points of support $= \dfrac{W^2L}{24P^2}$.

$W =$ weight of tape in pounds between supports (a light tape $= 1.0\pm$ lb. per 100 ft.; a heavy tape $= 3.0\pm$ per 100 ft.).

$L =$ length in feet between supports.

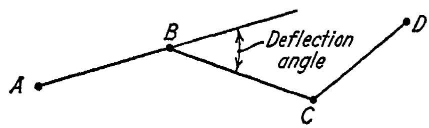
$P =$ tension used in pounds.

# MAPPING

## PLOTTING TRAVERSES

### 1. Plotting by Protractor

**Procedure.** Fix position of first line, and lay off its length $AB$ by

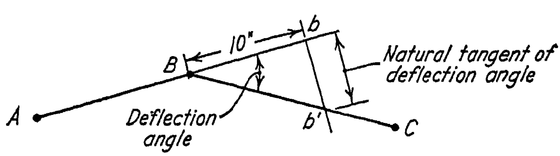



scaling. Orient the protractor at the forward point $B$; lay off the deflection angle to the succeeding line, and draw a light line of indefinite length. Scale off the given distance $BC$ to the next traverse point $C$, etc.

**Hints and Precautions.** Orient the position of the first line so that the succeeding lines will not run off the paper. Carefully check the deflection angles as to their direction right or left. Calculated bearings should check reasonably with observed magnetic bearings. When azimuths or calculated bearings are used, a meridian line may be drawn through each station and the direction of the succeeding line laid off from the meridian.

### 2. Plotting by Tangents

**Procedure.** Fix position of first line, and lay off its length $AB$ by



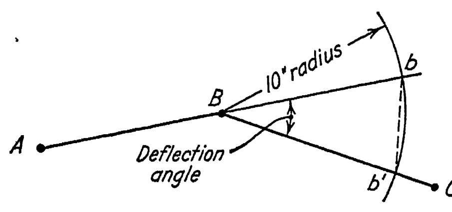

scaling. Prolong the line $AB$ some convenient distance, to form a base line $Bb$. Erect a perpendicular $bb'$ of sufficient length. Scale off the distance $bb'$ equal to the length of the base line $Bb$ multiplied by the natural tangent of the deflection angle. Draw a line from $B$ through $b'$ to define the direction of $BC$, etc.

**Hints and Precautions.** Time and accuracy can be gained by laying off the base line $Bb$ 10 in. in length and scaling off the natural tangent along the perpendicular with an engineer's scale. Because the 50 scale has more graduations than the 10 scale, it is customary to scale off one-half the natural tangent with the 50 scale. Scale all distances and erect all perpendiculars carefully. Where the deflection angle is greater than 90° the perpendicular is erected by measuring the base line back on the course from the last point and scaling off the tangent for 180°—the deflection angle. When the deflection angle is greater than 45°, erect a perpendicular from the last point set, scale off a 10-in. base line, and erect a line parallel to the last course, along which scale off the cotangent of the deflection angle. Check all plotted angles with a protractor. For in-

creased accuracy the base lines may be made 20 in. and the tangents scaled direct with the 50 scale. For checking the erected perpendiculars the diagonal distance on the hypotenuse of the 10-in. sides should scale 14.14 in.

### 3. Plotting by Chords

**Procedure.** Proceed the same as in plotting by tangents except that, instead of erecting a perpendicular at the end of the 10-in. base line, describe an arc of 10-in. radius. Scale the chord distance $bb'$. Draw a




line through $Bb'$, and plot the distance $BC$. The length of the chord $bb'$ is equal to $20 \cdot \sin \frac{1}{2}$, the deflection angle.

**Hints and Precautions.** In swinging the 10-in. arc use a beam compass or improvise one by inserting a needle point and a pencil point exactly 10 in. apart in a thin strip of wood. If a table of chords is available no computations are necessary. Check the plotted angles with a protractor.

### 4. Plotting by Rectangular Coordinates—Latitudes and Departures

**Procedure.** (1) Transpose the survey data to a computation book as shown in the sample form on p. 247. (2) Compute the latitudes and departures of the courses, and, if a closed traverse, balance the survey. Assume one of the traverse points as the origin of coordinates, calculate total latitudes and departures, and check the computations. (3) Determine the size of the enclosing rectangle, the four sides of which pass through the eastern, western, northern, and southern points of the traverse. (4) Plot the enclosing rectangle to required scale on drawing paper, estimating its position on the sheet by means of a small-scale sketch. Place the traverse symmetrical with the sheet (the sides of the rectangle may or may not be parallel to the edges of the paper). (5) Test the accuracy of the plotting by scaling the length of diagonals. Plot the reference meridian, and plot and check the reference parallel. (6) Construct coordinate lines (other meridians and parallels) so that the area will be divided in squares with sides less than the length of the scale to be used. Number each of these lines with its distance from the reference meridian or parallel. (7) Locate each traverse point by plotting its lati-

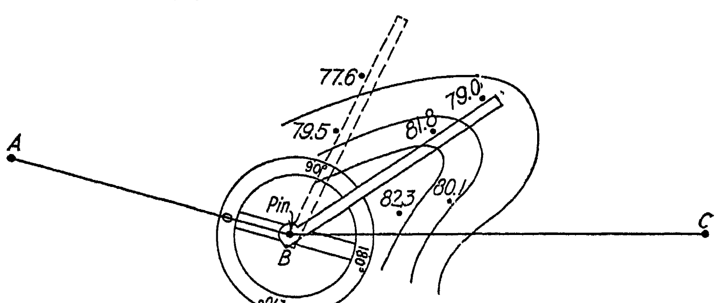
tude and departure. (8) Check the length of the traverse lines connecting the points by scaling, and check the angles with the protractor.

**Hints and Precautions.** Accurately construct the meridians and parallels. After the enclosing triangle has been constructed and adjusted by trial the other lines should be plotted entirely by scaling. Do not use a T-square and triangles in the usual way but use straightedges only. The best way to lay out the rectangle and coordinates is with a beam compass and steel straightedge, checking all rectangles by diagonals. If the southwest corner of the enclosing rectangle is taken as the origin of coordinates, all the total latitudes and departures will be positive.

**Practical Applications.** Plotting by coordinates is the best method for plotting most traverses. When the area of a closed traverse is to be computed the latitudes and departures are necessary. The size and shape of the drawing can be determined before plotting. Errors of plotting are not cumulative. The method of checking is simple, and in closed traverses the survey is balanced before plotting.

## PLOTTING TOPOGRAPHY

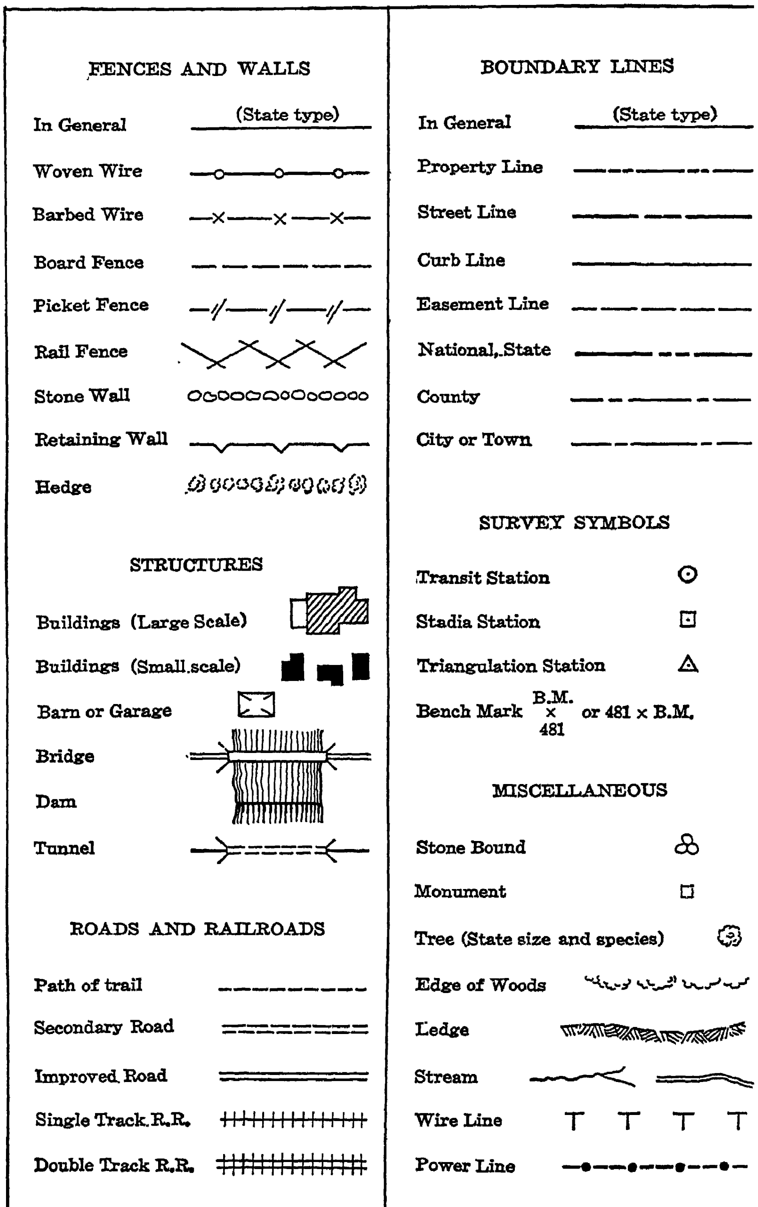
### 1. Stadia Topography by Protractor



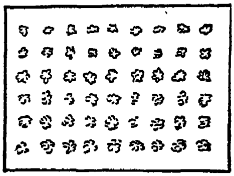

**Procedure.** First lay out the traverse from which topography was taken. To facilitate plotting use a full circle protractor and a scale that can be pinned at the center. Orient the zero of the protractor on the line to the point on which the transit was sighted in the field. Move the scale to the horizontal angle desired and lay off the horizontal distance.

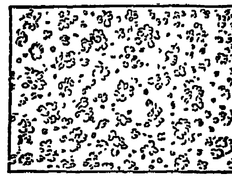
**Hints and Precautions.** One way of marking points as they are plotted is to note the elevation; another is to note the number of the point. Points which are to be connected should be connected before beginning a new station, i.e., points along a road, corners of a building, etc. When each traverse point occupied requires the plotting of a considerable number of points, speed and accuracy will be attained by two persons working as a team, one reading the notes and the other plotting the points.

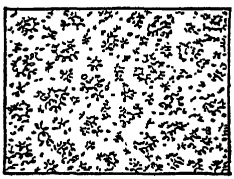
# MAPPING SYMBOLS *

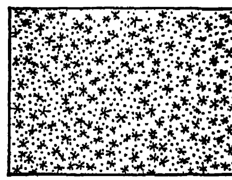


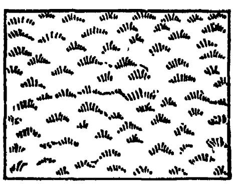

* *From Tracy, Surveying Theory and Practice. John Wiley & Sons.*

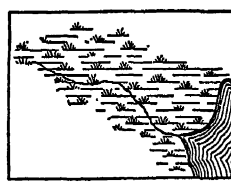

Orchard


Deciduous Trees

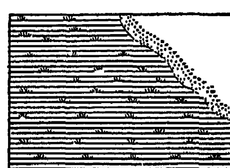

Oak Trees

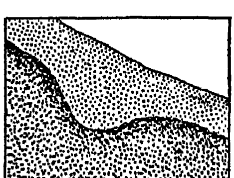

Pine Trees

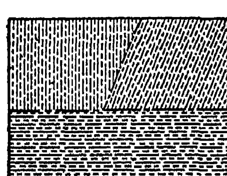

Meadow Land

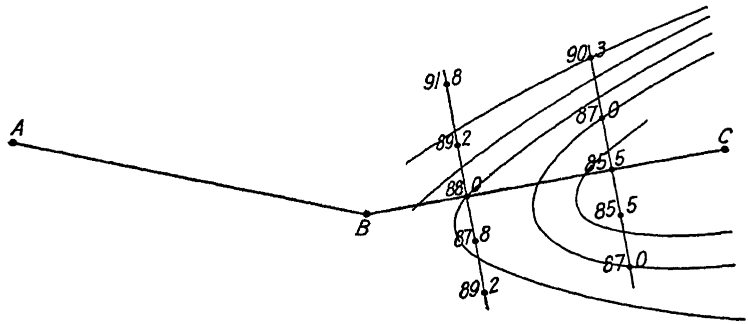

Fresh Marsh and Pond


Wooded Marsh


Salt Marsh


Sand-High and Low Water

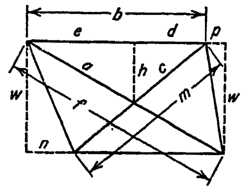

Cultivated Land



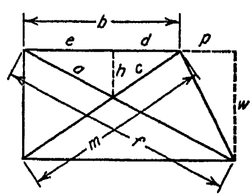

**2. Topography from Cross Sections**

**Procedure.** Indicate the line of cross sections by drawing a light line on the map. Scale off the distance right or left from the base line and mark the elevation.

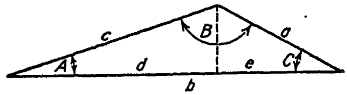
**Hints and Precautions.** Orient the base line so that right on the map corresponds to right in the notes.




| Given | To Find | Formula |
|---|---|---|
| *bpw* | *f* | $\sqrt{(b+p)^2+w^2}$ |
| *bnw* | *m* | $\sqrt{(b-n)^2+w^2}$ |
| *bnp* | *d* | $b(b-n) \div (2b+p-n)$ |
| *bnp* | *e* | $b(b+p) \div (2b+p-n)$ |
| *bfnp* | *a* | $bf \div (2b+p-n)$ |
| *bmnp* | *c* | $bm \div (2b+p-n)$ |
| *bnpw* | *h* | $bw \div (2b+p-n)$ |
| *afw* | *h* | $aw \div f$ |
| *cmw* | *h* | $cw \div m$ |



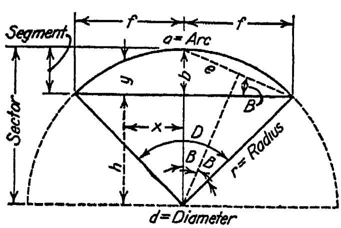

| Given | To Find | Formula |
|---|---|---|
| *bpw* | *f* | $\sqrt{(b+p)^2+w^2}$ |
| *bw* | *m* | $\sqrt{b^2+w^2}$ |
| *bp* | *d* | $b^2 \div (2b+p)$ |
| *bp* | *e* | $b(b+p) \div (2b+p)$ |
| *bfp* | *a* | $bf \div (2b+p)$ |
| *bmp* | *c* | $bm \div (2b+p)$ |
| *bpw* | *h* | $bw \div (2b+p)$ |
| *afw* | *h* | $aw \div f$ |
| *cmw* | *h* | $cw \div m$ |

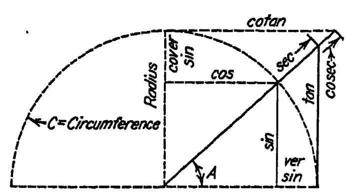



$$s = \frac{a+b+c}{2}$$

| Given | To Find | Formula |
|---|---|---|
| $ABa$ | $b$ | $a \sin B \div \sin A$ |
| $ABa$ | $c$ | $a \sin (A+B) \div \sin A$ |
| $ABb$ | $a$ | $b \sin A \div \sin B$ |
| $ABb$ | $c$ | $b \sin (A+B) \div \sin B$ |
| $ABc$ | $a$ | $c \sin A \div \sin (A+B)$ |
| $ABc$ | $b$ | $c \sin B \div \sin (A+B)$ |
| $ACa$ | $b$ | $a \sin (A+C) \div \sin A$ |
| $ACa$ | $c$ | $a \sin C \div \sin A$ |
| $ACb$ | $a$ | $b \sin A \div \sin (A+C)$ |
| $ACb$ | $c$ | $b \sin C \div \sin (A+C)$ |
| $ACc$ | $a$ | $c \sin A \div \sin C$ |
| $ACc$ | $b$ | $c \sin (A+C) \div \sin C$ |
| $BCa$ | $b$ | $a \sin B \div \sin (B+C)$ |
| $BCa$ | $c$ | $a \sin C \div \sin (B+C)$ |
| $BCb$ | $a$ | $b \sin (B+C) \div \sin B$ |
| $BCb$ | $c$ | $b \sin C \div \sin B$ |
| $BCc$ | $a$ | $c \sin (B+C) \div \sin C$ |
| $BCc$ | $b$ | $c \sin B \div \sin C$ |
| $abc$ | $S$ | $(a+b+c) \div 2$ |
| $abcs$ | $A$ | $\sin \frac{1}{2}A = \sqrt{(s-b)(s-c) \div bc}$ |
| $abcs$ | $A$ | $\cos \frac{1}{2}A = \sqrt{s(s-a) \div bc}$ |
| $abcs$ | $A$ | $\tan \frac{1}{2}A = \sqrt{(s-b)(s-c) \div s(s-a)}$ |
| $abcs$ | $B$ | $\sin \frac{1}{2}B = \sqrt{(s-a)(s-c) \div ac}$ |
| $abcs$ | $B$ | $\cos \frac{1}{2}B = \sqrt{s(s-b) \div ac}$ |
| $abcs$ | $B$ | $\tan \frac{1}{2}B = \sqrt{(s-a)(s-c) \div s(s-b)}$ |
| $abcs$ | $C$ | $\sin \frac{1}{2}C = \sqrt{(s-a)(s-b) \div ab}$ |
| $abcs$ | $C$ | $\cos \frac{1}{2}C = \sqrt{s(s-c) \div ab}$ |
| $abcs$ | $C$ | $\tan \frac{1}{2}C = \sqrt{(s-a)(s-b) \div s(s-c)}$ |
| $abcs$ | $d$ | $(b^2+c^2-a^2) \div 2b$ |
| $abcs$ | $e$ | $(a^2+b^2-c^2) \div 2b$ |
| $Aab$ | $B$ | $\sin = b \sin A \div a$ |
| $Aac$ | $C$ | $\sin = c \sin A \div a$ |
| $Bab$ | $A$ | $\sin = a \sin B \div b$ |
| $Bbc$ | $C$ | $\sin = c \sin B \div b$ |
| $Cac$ | $A$ | $\sin = a \sin C \div c$ |
| $Cbc$ | $B$ | $\sin = b \sin C \div c$ |
| $Abc$ | $\frac{1}{2}(B+C)$ | $90° - \frac{1}{2}A$ |

| Given | To Find | Formula |
|---|---|---|
| $Abc$ | $\frac{1}{2}(B - C)$ | $\tan = [(b - c)\tan(90° - \frac{1}{2}A)] \div (b + c)$ |
| $Abc$ | $B$ | $\frac{1}{2}(B + C) + \frac{1}{2}(B - C)$ |
| $Abc$ | $C$ | $\frac{1}{2}(B + C) - \frac{1}{2}(B - C)$ |
| $Abc$ | $a$ | $\sqrt{b^2 + c^2 - 2bc\cos A}$ |
| $Bac$ | $\frac{1}{2}(A + C)$ | $90° - \frac{1}{2}B$ |
| $Bac$ | $\frac{1}{2}(A - C)$ | $\tan = [(a - c)\tan(90° - \frac{1}{2}B)] \div (a + c)$ |
| $Bac$ | $A$ | $\frac{1}{2}(A + C) + \frac{1}{2}(A - C)$ |
| $Bac$ | $C$ | $\frac{1}{2}(A + C) - \frac{1}{2}(A - C)$ |
| $Bac$ | $b$ | $\sqrt{a^2 + c^2 - 2ac\cos B}$ |
| $Cab$ | $\frac{1}{2}(A + B)$ | $90° - \frac{1}{2}C$ |
| $Cab$ | $\frac{1}{2}(A - B)$ | $\tan = [(a - b)\tan(90° - \frac{1}{2}C)] \div (a + b)$ |
| $Cab$ | $A$ | $\frac{1}{2}(A + B) + \frac{1}{2}(A - B)$ |
| $Cab$ | $B$ | $\frac{1}{2}(A + B) - \frac{1}{2}(A - B)$ |
| $Cab$ | $c$ | $\sqrt{a^2 + b^2 - 2ab\cos C}$ |




| Given | To Find | Formula |
|---|---|---|
| $drB$ | $b$ | $d\sin^2 B$ |
| $drB$ | $f$ | $r\sin 2B$ |
| $drB$ | $e$ | $d\sin B$ |
| $drb$ | Ang $B$ | $\sin B = \sqrt{b \div d}$ |
| $drb$ | $f$ | $\sqrt{b(d - b)}$ |
| $drb$ | $e$ | $\sqrt{db}$ |
| $dre$ | Ang $B$ | $\sin B = e \div d$ |
| $dre$ | $b$ | $e^2 \div d$ |
| $dre$ | $f$ | $e\sqrt{d^2 - e^2} \div d$ |
| $bB$ | $r$ | $\frac{1}{2}b \div \sin^2 B$ |
| $eB$ | $r$ | $\frac{1}{2}e \div \sin B$ |
| $bf$ | Ang $B$ | $\tan B = b \div f$ |

| Given | To Find | Formula |
|---|---|---|
| $bf$ | $r$ | $(f^2 + b^2) \div 2b$ |
| $fe$ | Ang $B$ | $\sin B = \sqrt{e^2 - f^2} \div e$ |
| $fe$ | $r$ | $\frac{1}{2}e^2 \div \sqrt{e^2 - f^2}$ |
| $be$ | Ang $B$ | $\sin B = b \div e$ |
| $be$ | $r$ | $\frac{1}{2}e^2 \div b$ |
| $rxy$ | Ang $B$ | $\cos 2B = (\sqrt{r^2 - x^2} - y) \div r$ |
| $rxy$ | $b$ | $r + y - \sqrt{r^2 - x^2}$ |
| $brx$ | $y$ | $b + \sqrt{r^2 - x^2} - r$ |
| $bry$ | $x$ | $\sqrt{r^2 - (r + y - b)^2}$ |
| $bxy$ | $r$ | $[x^2 + (b - y)^2] \div (2b - 2y)$ |
| $r$ | Circ | $6.2832r$ |
| $rD$ | Arc $a$ | $.0174533rD°$ |
| $rD$ | Arc $a$ | $.0002909\ rD'$ |
| $rD$ | Arc $a$ | $.00000485\ rD''$ |
| $r$ | Area | Circle $= 3.1416\ r^2$ |
| $d$ | Area | Circle $= 0.7854\ d^2$ |
| $c$ | Area | Circle $= 0.0796\ c^2$ |
| $ar$ | Area | Sector $= 0.5\ ar$ |
| $arfh$ | Area | Segment $= 0.5$ ar $- fh$ |

# TABLE 20. NATURAL TRIGONOMETRIC FUNCTIONS *

| Deg. | Min. | Sine | Covers | Cosec | Tan | Cotan | Secant | Versin | Cosine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | **0** | **0.00000** | **1.00000** | **Infinite** | **0.00000** | **Infinite** | **1.0000** | **0.00000** | **1.00000** | **90** | **0** |
| | 15 | .00436 | .99564 | 229.18 | .00436 | 229.18 | 1.0000 | .00001 | .99999 | | 45 |
| | 30 | .00873 | .99127 | 114.59 | .00873 | 114.59 | 1.0000 | .00004 | .99996 | | 30 |
| | 45 | .01309 | .98691 | 76.397 | .01309 | 76.390 | 1.0001 | .00009 | .99991 | | 15 |
| **1** | **0** | **.01745** | **.98255** | **57.299** | **.01745** | **57.290** | **1.0001** | **.00015** | **.99985** | **89** | **0** |
| | 15 | .02181 | .97819 | 45.840 | .02182 | 45.829 | 1.0002 | .00024 | .99976 | | 45 |
| | 30 | .02618 | .97382 | 38.202 | .02618 | 38.188 | 1.0003 | 00034 | .99966 | | 30 |
| | 45 | .03054 | .96946 | 32.746 | .03055 | 32.730 | 1.0005 | .00047 | .99953 | | 15 |
| **2** | **0** | **.03490** | **.96510** | **28.654** | **.03492** | **28.636** | **1.0006** | **.00061** | **.99939** | **88** | **0** |
| | 15 | .03926 | .96074 | 25.471 | .03929 | 25.452 | 1.0008 | .00077 | .99923 | | 45 |
| | 30 | .04362 | .95638 | 22.926 | .04366 | 22.904 | 1.0009 | .00095 | .99905 | | 30 |
| | 45 | .04798 | .95202 | 20.843 | .04803 | 20.819 | 1.0011 | .00115 | .99885 | | 15 |
| **3** | **0** | **.05234** | **.94766** | **19.107** | **.05241** | **19.081** | **1.0014** | **.00137** | **.99863** | **87** | **0** |
| | 15 | .05669 | .94331 | 17.639 | .05678 | 17.611 | 1.0016 | .00161 | .99839 | | 45 |
| | 30 | .06105 | .93895 | 16.380 | .06116 | 16.350 | 1.0019 | .00187 | .99813 | | 30 |
| | 45 | .06540 | .93460 | 15.290 | .06554 | 15.257 | 1.0021 | .00214 | .99786 | | 15 |
| **4** | **0** | **.06976** | **.93024** | **14.336** | **.06993** | **14.301** | **1.0024** | **.00244** | **.99756** | **86** | **0** |
| | 15 | .07411 | .92589 | 13.494 | .07431 | 13.457 | 1.0028 | .00275 | .99725 | | 45 |
| | 30 | .07846 | .92154 | 12.745 | .07870 | 12.706 | 1.0031 | .00308 | .99692 | | 30 |
| | 45 | .08281 | .91719 | 12.076 | .08309 | 12.035 | 1.0034 | .00343 | .99656 | | 15 |
| **5** | **0** | **.08716** | **.91284** | **11.474** | **.08749** | **11.430** | **1.0038** | **.00381** | **.99619** | **85** | **0** |
| | 15 | .09150 | .90850 | 10.929 | .09189 | 10.883 | 1.0042 | .00420 | .99580 | | 45 |
| | 30 | .09585 | .90415 | 10.433 | .09629 | 10.385 | 1.0046 | .00460 | .99540 | | 30 |
| | 45 | .10019 | .89981 | 9.9812 | .10069 | 9.9310 | 1.0051 | .00503 | .99497 | | 15 |
| **6** | **0** | **.10453** | **.89547** | **9.5668** | **.10510** | **9.5144** | **1.0055** | **.00548** | **.99452** | **84** | **0** |
| | 15 | .10887 | .89113 | 9.1855 | .10952 | 9.1309 | 1.0060 | .00594 | .99406 | | 45 |
| | 30 | .11320 | .88680 | 8.8337 | .11393 | 8.7769 | 1.0065 | .00643 | .99357 | | 30 |
| | 45 | .11754 | .88246 | 8.5079 | .11836 | 8.4490 | 1.0070 | .00693 | .99307 | | 15 |
| **7** | **0** | **.12187** | **.87813** | **8.2055** | **.12278** | **8.1443** | **1.0075** | **.00745** | **.99255** | **83** | **0** |
| | 15 | .12620 | .87380 | 7.9240 | .12722 | 7.8606 | 1.0081 | .00800 | .99200 | | 45 |
| | 30 | .13053 | .86947 | 7.6613 | .13165 | 7.5958 | 1.0086 | .00856 | .99144 | | 30 |
| | 45 | .13485 | .86515 | 7.4156 | .13609 | 7.3479 | 1.0092 | .00913 | .99086 | | 15 |
| **8** | **0** | **.13917** | **.86083** | **7.1853** | **.14054** | **7.1154** | **1.0098** | **.00973** | **.99027** | **82** | **0** |
| | 15 | .14349 | .85651 | 6.9690 | .14499 | 6.8969 | 1.0105 | .01035 | .98965 | | 45 |
| | 30 | .14781 | .85219 | 6.7655 | .14945 | 6.6912 | 1.0111 | .01098 | .98902 | | 30 |
| | 45 | .15212 | .84788 | 6.5736 | .15391 | 6.4971 | 1.0118 | .01164 | .98836 | | 15 |
| **9** | **0** | **.15643** | **.84357** | **6.3924** | **.15838** | **6.3138** | **1.0125** | **.01231** | **.98769** | **81** | **0** |
| | 15 | .16074 | .83926 | 6.2211 | .16286 | 6.1402 | 1.0132 | .01300 | .98700 | | 45 |
| | 30 | .16505 | .83495 | 6.0589 | .16734 | 5.9758 | 1.0139 | .01371 | .98629 | | 30 |
| | 45 | .16935 | .83065 | 5.9049 | .17183 | 5.8197 | 1.0147 | .01444 | .98556 | | 15 |
| **10** | **0** | **.17365** | **.82635** | **5.7588** | **.17633** | **5.6713** | **1.0154** | **.01519** | **.98481** | **80** | **0** |
| | 15 | .17794 | .82206 | 5.6198 | .18083 | 5.5301 | 1.0162 | .01596 | .98404 | | 45 |
| | 30 | .18224 | .81776 | 5.4874 | .18534 | 5.3955 | 1.0170 | .01675 | .98325 | | 30 |
| | 45 | .18652 | .81348 | 5.3612 | .18986 | 5.2672 | 1.0179 | .01755 | .98245 | | 15 |
| **11** | **0** | **.19081** | **.80919** | **5.2408** | **.19438** | **5.1446** | **1.0187** | **.01837** | **.98163** | **79** | **0** |
| | 15 | .19509 | .80491 | 5.1258 | .19891 | 5.0273 | 1.0196 | .01921 | .98079 | | 45 |
| | 30 | .19937 | .80063 | 5.0158 | .20345 | 4.9152 | 1.0205 | .02008 | .97992 | | 30 |
| | 45 | .20364 | .79636 | 4.9106 | .20800 | 4.8077 | 1.0214 | .02095 | .97905 | | 15 |
| **12** | **0** | **.20791** | **.79209** | **4.8097** | **.21256** | **4.7046** | **1.0223** | **.02185** | **.97815** | **78** | **0** |
| | 15 | .21218 | .78782 | 4.7130 | .21712 | 4.6057 | 1.0233 | .02277 | .97723 | | 45 |
| | 30 | .21644 | .78356 | 4.6202 | .22169 | 4.5107 | 1.0243 | .02370 | .97630 | | 30 |
| | 45 | .22070 | .77930 | 4.5311 | .22628 | 4.4194 | 1.0253 | .02466 | .97534 | | 15 |
| **13** | **0** | **.22495** | **.77505** | **4.4454** | **.23087** | **4.3315** | **1.0263** | **.02563** | **.97437** | **77** | **0** |
| | 15 | .22920 | .77080 | 4.3630 | .23547 | 4.2468 | 1.0273 | .02662 | .97338 | | 45 |
| | 30 | .23345 | .76655 | 4.2837 | .24008 | 4.1653 | 1.0284 | .02763 | .97237 | | 30 |
| | 45 | .23769 | .76231 | 4.2072 | .24470 | 4.0867 | 1.0295 | .02866 | .97134 | | 15 |
| **14** | **0** | **.24192** | **.75808** | **4.1336** | **.24933** | **4.0108** | **1.0306** | **.02970** | **.97030** | **76** | **0** |
| | 15 | .24615 | .75385 | 4.0625 | .25397 | 3.9375 | 1.0317 | .03077 | .96923 | | 45 |
| | 30 | .25038 | .74962 | 3.9939 | .25862 | 3.8667 | 1.0329 | .03185 | .96815 | | 30 |
| | 45 | .25460 | .74540 | 3.9277 | .26328 | 3.7983 | 1.0341 | .03295 | .96705 | | 15 |
| **15** | **0** | **.25882** | **.74118** | **3.8637** | **.26795** | **3.7320** | **1.0353** | **.03407** | **.96593** | **75** | **0** |
| | | Cosine | Versin | Secant | Cotan | Tan | Cosec | Covers | Sine | Deg. | Min. |

**From 75° to 90° read from bottom of table upwards.**

* *From Peele, Mining Engineers' Handbook, John Wiley & Sons.*

| Deg. | Min. | Sine | Covers | Cosec | Tan | Cotan | Secant | Versin | Cosine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **15** | **0** | **0.25882** | **0.74118** | **3.8637** | **0.26795** | **3.7320** | **1.0353** | **0.03407** | **0.96593** | **75** | **0** |
| | 15 | .26303 | .73697 | 3.8018 | .27263 | 3.6680 | 1.0365 | .03521 | .96479 | | 45 |
| | 30 | .26724 | .73276 | 3.7420 | .27732 | 3.6059 | 1.0377 | .03637 | .96363 | | 30 |
| | 45 | .27144 | .72856 | 3.6840 | .28203 | 3.5457 | 1.0390 | .03754 | .96246 | | 15 |
| **16** | **0** | **.27564** | **.72436** | **3.6280** | **.28674** | **3.4874** | **1.0403** | **.03874** | **.96126** | **74** | **0** |
| | 15 | .27983 | .72017 | 3.5736 | .29147 | 3.4308 | 1.0416 | .03995 | .96005 | | 45 |
| | 30 | .28402 | .71598 | 3.5209 | .29621 | 3.3759 | 1.0429 | .04118 | .95882 | | 30 |
| | 45 | .28820 | .71180 | 3.4699 | .30096 | 3.3226 | 1.0443 | .04243 | .95757 | | 15 |
| **17** | **0** | **.29237** | **.70763** | **3.4203** | **.30573** | **3.2709** | **1.0457** | **.04370** | **.95630** | **73** | **0** |
| | 15 | .29654 | .70346 | 3.3722 | .31051 | 3.2205 | 1.0471 | .04498 | .95502 | | 45 |
| | 30 | .30070 | .69929 | 3.3255 | .31530 | 3.1716 | 1.0485 | .04628 | .95372 | | 30 |
| | 45 | .30486 | .69514 | 3.2801 | .32010 | 3.1240 | 1.0500 | .04760 | .95240 | | 15 |
| **18** | **0** | **.30902** | **.69098** | **3.2361** | **.32492** | **3.0777** | **1.0515** | **.04894** | **.95106** | **72** | **0** |
| | 15 | .31316 | .68684 | 3.1932 | .32975 | 3.0326 | 1.0530 | .05030 | .94970 | | 45 |
| | 30 | .31730 | .68270 | 3.1515 | .33459 | 2.9887 | 1.0545 | .05168 | .94832 | | 30 |
| | 45 | .32144 | .67856 | 3.1110 | .33945 | 2.9459 | 1.0560 | .05307 | .94693 | | 15 |
| **19** | **0** | **.32557** | **.67443** | **3.0715** | **.34433** | **2.9042** | **1.0576** | **.05448** | **.94552** | **71** | **0** |
| | 15 | .32969 | .67031 | 3.0331 | .34921 | 2.8636 | 1.0592 | .05591 | .94409 | | 45 |
| | 30 | .33381 | .66619 | 2.9957 | .35412 | 2.8239 | 1.0608 | .05736 | .94264 | | 30 |
| | 45 | .33792 | .66208 | 2.9593 | .35904 | 2.7852 | 1.0625 | .05882 | .94118 | | 15 |
| **20** | **0** | **.34202** | **.65798** | **2.9238** | **.36397** | **2.7475** | **1.0642** | **.06031** | **.93969** | **70** | **0** |
| | 15 | .34612 | .65388 | 2.8892 | .36892 | 2.7106 | 1.0659 | .06181 | .93819 | | 45 |
| | 30 | .35021 | .64979 | 2.8554 | .37388 | 2.6746 | 1.0676 | .06333 | .93667 | | 30 |
| | 45 | .35429 | .64571 | 2.8225 | .37887 | 2.6395 | 1.0694 | .06486 | .93514 | | 15 |
| **21** | **0** | **.35837** | **.64163** | **2.7904** | **.38386** | **2.6051** | **1.0711** | **.06642** | **.93358** | **69** | **0** |
| | 15 | .36244 | .63756 | 2.7591 | .38888 | 2.5715 | 1.0729 | .06799 | .93201 | | 45 |
| | 30 | .36650 | .63350 | 2.7285 | .39391 | 2.5386 | 1.0748 | .06958 | .93042 | | 30 |
| | 45 | .37056 | .62944 | 2.6986 | .39896 | 2.5065 | 1.0766 | .07119 | .92881 | | 15 |
| **22** | **0** | **.37461** | **.62539** | **2.6695** | **.40403** | **2.4751** | **1.0785** | **.07282** | **.92718** | **68** | **0** |
| | 15 | .37865 | .62135 | 2.6410 | .40911 | 2.4443 | 1.0804 | .07446 | .92554 | | 45 |
| | 30 | .38268 | .61732 | 2.6131 | .41421 | 2.4142 | 1.0824 | .07612 | .92388 | | 30 |
| | 45 | .38671 | .61329 | 2.5859 | .41933 | 2.3847 | 1.0844 | .07780 | .92220 | | 15 |
| **23** | **0** | **.39073** | **.60927** | **2.5593** | **.42447** | **2.3559** | **1.0864** | **.07950** | **.92050** | **67** | **0** |
| | 15 | .39474 | .60526 | 2.5333 | .42963 | 2.3276 | 1.0884 | .08121 | .91879 | | 45 |
| | 30 | .39875 | .60125 | 2.5078 | .43481 | 2.2998 | 1.0904 | .08294 | .91706 | | 30 |
| | 45 | .40275 | .59725 | 2.4829 | .44001 | 2.2727 | 1.0925 | .08469 | .91531 | | 15 |
| **24** | **0** | **.40674** | **.59326** | **2.4586** | **.44523** | **2.2460** | **1.0946** | **.08645** | **.91355** | **66** | **0** |
| | 15 | .41072 | .58928 | 2.4348 | .45047 | 2.2199 | 1.0968 | .08824 | .91176 | | 45 |
| | 30 | .41469 | .58531 | 2.4114 | .45573 | 2.1943 | 1.0989 | .09004 | .90996 | | 30 |
| | 45 | .41866 | .58134 | 2.3886 | .46101 | 2.1692 | 1.1011 | .09186 | .90814 | | 15 |
| **25** | **0** | **.42262** | **.57738** | **2.3662** | **.46631** | **2.1445** | **1.1034** | **.09369** | **.90631** | **65** | **0** |
| | 15 | .42657 | .57343 | 2.3443 | .47163 | 2.1203 | 1.1056 | .09554 | .90446 | | 45 |
| | 30 | .43051 | .56949 | 2.3228 | .47697 | 2.0965 | 1.1079 | .09741 | .90259 | | 30 |
| | 45 | .43445 | .56555 | 2.3018 | .48234 | 2.0732 | 1.1102 | .09930 | .90070 | | 15 |
| **26** | **0** | **.43837** | **.56163** | **2.2812** | **.48773** | **2.0503** | **1.1126** | **.10121** | **.89879** | **64** | **0** |
| | 15 | .44229 | .55771 | 2.2610 | .49314 | 2.0278 | 1.1150 | .10313 | .89687 | | 45 |
| | 30 | .44620 | .55380 | 2.2412 | .49858 | 2.0057 | 1.1174 | .10507 | .89493 | | 30 |
| | 45 | .45010 | .54990 | 2.2217 | .50404 | 1.9840 | 1.1198 | .10702 | .89298 | | 15 |
| **27** | **0** | **.45399** | **.54601** | **2.2027** | **.50952** | **1.9626** | **1.1223** | **.10899** | **.89101** | **63** | **0** |
| | 15 | .45787 | .54213 | 2.1840 | .51503 | 1.9416 | 1.1248 | .11098 | .88902 | | 45 |
| | 30 | .46175 | .53825 | 2.1657 | .52057 | 1.9210 | 1.1274 | .11299 | .88701 | | 30 |
| | 45 | .46561 | .53439 | 2.1477 | .52612 | 1.9007 | 1.1300 | .11501 | .88499 | | 15 |
| **28** | **0** | **.46947** | **.53053** | **2.1300** | **.53171** | **1.8807** | **1.1326** | **.11705** | **.88295** | **62** | **0** |
| | 15 | .47332 | .52668 | 2.1127 | .53732 | 1.8611 | 1.1352 | .11911 | .88089 | | 45 |
| | 30 | .47716 | .52284 | 2.0957 | .54295 | 1.8418 | 1.1379 | .12118 | .87882 | | 30 |
| | 45 | .48099 | .51901 | 2.0790 | .54862 | 1.8228 | 1.1406 | .12327 | .87673 | | 15 |
| **29** | **0** | **.48481** | **.51519** | **2.0627** | **.55431** | **1.8040** | **1.1433** | **.12538** | **.87462** | **61** | **0** |
| | 15 | .48862 | .51138 | 2.0466 | .56003 | 1.7856 | 1.1461 | .12750 | .87250 | | 45 |
| | 30 | .49242 | .50758 | 2.0308 | .56577 | 1.7675 | 1.1490 | .12964 | .87036 | | 30 |
| | 45 | .49622 | .50378 | 2.0152 | .57155 | 1.7496 | 1.1518 | .13180 | .86820 | | 15 |
| **30** | **0** | **.50000** | **.50000** | **2.0000** | **.57735** | **1.7320** | **1.1547** | **.13397** | **.86603** | **60** | **0** |
| | | Cosine | Versin | Secant | Cotan | Tan | Cosec | Covers | Sine | Deg. | Min. |

From 60° to 75° read from bottom of table upwards.

| Deg. | Min. | Sine | Covers | Cosec | Tan | Cotan | Secant | Versin | Cosine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **30** | **0** | **0.50000** | **0.50000** | **2.0000** | **0.57735** | **1.7320** | **1.1547** | **0.13397** | **0.86603** | **60** | **0** |
| | 15 | .50377 | .49623 | 1.9850 | .58318 | 1.7147 | 1.1576 | .13616 | .86384 | | 45 |
| | 30 | .50754 | .49246 | 1.9703 | .58904 | 1.6977 | 1.1606 | .13837 | .86163 | | 30 |
| | 45 | .51129 | .48871 | 1.9558 | .59494 | 1.6808 | 1.1636 | .14059 | .85941 | | 15 |
| **31** | **0** | **.51504** | **.48496** | **1.9416** | **.60086** | **1.6643** | **1.1666** | **.14283** | **.85717** | **59** | **0** |
| | 15 | .51877 | .48123 | 1.9276 | .60681 | 1.6479 | 1.1697 | .14509 | .85491 | | 45 |
| | 30 | .52250 | .47750 | 1.9139 | .61280 | 1.6319 | 1.1728 | .14736 | .85264 | | 30 |
| | 45 | .52621 | .47379 | 1.9004 | .61882 | 1.6160 | 1.1760 | .14965 | .85035 | | 15 |
| **32** | **0** | **.52992** | **.47008** | **1.8871** | **.62487** | **1.6003** | **1.1792** | **.15195** | **.84805** | **58** | **0** |
| | 15 | .53361 | .46639 | 1.8740 | .63095 | 1.5849 | 1.1824 | .15427 | .84573 | | 45 |
| | 30 | .53730 | .46270 | 1.8612 | .63707 | 1.5697 | 1.1857 | .15661 | .84339 | | 30 |
| | 45 | .54097 | .45903 | 1.8485 | .64322 | 1.5547 | 1.1890 | .15896 | .84104 | | 15 |
| **33** | **0** | **.54464** | **.45536** | **1.8361** | **.64941** | **1.5399** | **1.1924** | **.16133** | **.83867** | **57** | **0** |
| | 15 | .54829 | .45171 | 1.8238 | .65563 | 1.5253 | 1.1958 | .16371 | .83629 | | 45 |
| | 30 | .55194 | .44806 | 1.8118 | .66188 | 1.5108 | 1.1992 | .16611 | .83389 | | 30 |
| | 45 | .55557 | .44443 | 1.7999 | .66818 | 1.4966 | 1.2027 | .16853 | .83147 | | 15 |
| **34** | **0** | **.55919** | **.44081** | **1.7883** | **.67451** | **1.4826** | **1.2062** | **.17096** | **.82904** | **56** | **0** |
| | 15 | .56280 | .43720 | 1.7768 | .68087 | 1.4687 | 1.2098 | .17341 | .82659 | | 45 |
| | 30 | .56641 | .43359 | 1.7655 | .68728 | 1.4550 | 1.2134 | .17587 | .82413 | | 30 |
| | 45 | .57000 | .43000 | 1.7544 | .69372 | 1.4415 | 1.2171 | .17835 | .82165 | | 15 |
| **35** | **0** | **.57358** | **.42642** | **1.7434** | **.70021** | **1.4281** | **1.2208** | **.18085** | **.81915** | **55** | **0** |
| | 15 | .57715 | .42285 | 1.7327 | .70673 | 1.4150 | 1.2245 | .18336 | .81664 | | 45 |
| | 30 | .58070 | .41930 | 1.7220 | .71329 | 1.4019 | 1.2283 | .18588 | .81412 | | 30 |
| | 45 | .58425 | .41575 | 1.7116 | .71990 | 1.3891 | 1.2322 | .18843 | .81157 | | 15 |
| **36** | **0** | **.58779** | **.41221** | **1.7013** | **.72654** | **1.3764** | **1.2361** | **.19098** | **.80902** | **54** | **0** |
| | 15 | .59131 | .40869 | 1.6912 | .73323 | 1.3638 | 1.2400 | .19356 | .80644 | | 45 |
| | 30 | .59482 | .40518 | 1.6812 | .73996 | 1.3514 | 1.2440 | .19614 | .80386 | | 30 |
| | 45 | .59832 | .40168 | 1.6713 | .74673 | 1.3392 | 1.2480 | .19875 | .80125 | | 15 |
| **37** | **0** | **.60181** | **.39819** | **1.6616** | **.75355** | **1.3270** | **1.2521** | **.20136** | **.79864** | **53** | **0** |
| | 15 | .60529 | .39471 | 1.6521 | .76042 | 1.3151 | 1.2563 | .20400 | .79600 | | 45 |
| | 30 | .60876 | .39124 | 1.6427 | .76733 | 1.3032 | 1.2605 | .20665 | .79335 | | 30 |
| | 45 | .61222 | .38778 | 1.6334 | .77428 | 1.2915 | 1.2647 | .20931 | .79069 | | 15 |
| **38** | **0** | **.61566** | **.38434** | **1.6243** | **.78129** | **1.2799** | **1.2690** | **.21199** | **.78801** | **52** | **0** |
| | 15 | .61909 | .38091 | 1.6153 | .78834 | 1.2685 | 1.2734 | .21468 | .78532 | | 45 |
| | 30 | .62251 | .37749 | 1.6064 | .79543 | 1.2572 | 1.2778 | .21739 | .78261 | | 30 |
| | 45 | .62592 | .37408 | 1.5976 | .80258 | 1.2460 | 1.2822 | .22012 | .77988 | | 15 |
| **39** | **0** | **.62932** | **.37068** | **1.5890** | **.80978** | **1.2349** | **1.2868** | **.22285** | **.77715** | **51** | **0** |
| | 15 | .63271 | .36729 | 1.5805 | .81703 | 1.2239 | 1.2913 | .22561 | .77439 | | 45 |
| | 30 | .63608 | .36392 | 1.5721 | .82434 | 1.2131 | 1.2960 | .22838 | .77162 | | 30 |
| | 45 | .63944 | .36056 | 1.5639 | .83169 | 1.2024 | 1.3007 | .23116 | .76884 | | 15 |
| **40** | **0** | **.64279** | **.35721** | **1.5557** | **.83910** | **1.1918** | **1.3054** | **.23396** | **.76604** | **50** | **0** |
| | 15 | .64612 | .35388 | 1.5477 | .84656 | 1.1812 | 1.3102 | .23677 | .76323 | | 45 |
| | 30 | .64945 | .35055 | 1.5398 | .85408 | 1.1708 | 1.3151 | .23959 | .76041 | | 30 |
| | 45 | .65276 | .34724 | 1.5320 | .86165 | 1.1606 | 1.3200 | .24244 | .75756 | | 15 |
| **41** | **0** | **.65606** | **.34394** | **1.5242** | **.86929** | **1.1504** | **1.3250** | **.24529** | **.75471** | **49** | **0** |
| | 15 | .65935 | .34065 | 1.5166 | .87698 | 1.1403 | 1.3301 | .24816 | .75184 | | 45 |
| | 30 | .66262 | .33738 | 1.5092 | .88472 | 1.1303 | 1.3352 | .25104 | .74896 | | 30 |
| | 45 | .66588 | .33412 | 1.5018 | .89253 | 1.1204 | 1.3404 | .25394 | .74606 | | 15 |
| **42** | **0** | **.66913** | **.33087** | **1.4945** | **.90040** | **1.1106** | **1.3456** | **.25686** | **.74314** | **48** | **0** |
| | 15 | .67237 | .32763 | 1.4873 | .90834 | 1.1009 | 1.3509 | .25978 | .74022 | | 45 |
| | 30 | .67559 | .32441 | 1.4802 | .91633 | 1.0913 | 1.3563 | .26272 | .73728 | | 30 |
| | 45 | .67880 | .32120 | 1.4732 | .92439 | 1.0818 | 1.3618 | .26568 | .73432 | | 15 |
| **43** | **0** | **.68200** | **.31800** | **1.4663** | **.93251** | **1.0724** | **1.3673** | **.26865** | **.73135** | **47** | **0** |
| | 15 | .68518 | .31482 | 1.4595 | .94071 | 1.0630 | 1.3729 | .27163 | .72837 | | 45 |
| | 30 | .68835 | .31165 | 1.4527 | .94896 | 1.0538 | 1.3786 | .27463 | .72537 | | 30 |
| | 45 | .69151 | .30849 | 1.4461 | .95729 | 1.0446 | 1.3843 | .27764 | .72236 | | 15 |
| **44** | **0** | **.69466** | **.30534** | **1.4396** | **.96569** | **1.0355** | **1.3902** | **.28066** | **.71934** | **46** | **0** |
| | 15 | .69779 | .30221 | 1.4331 | .97416 | 1.0265 | 1.3961 | .28370 | .71630 | | 45 |
| | 30 | .70091 | .29909 | 1.4267 | .98270 | 1.0176 | 1.4020 | .28675 | .71325 | | 30 |
| | 45 | .70401 | .29599 | 1.4204 | .99131 | 1.0088 | 1.4081 | .28981 | .71019 | | 15 |
| **45** | **0** | **.70711** | **.29289** | **1.4142** | **.10000** | **1.0000** | **1.4142** | **.29289** | **.70711** | **45** | **0** |
| | | Cosine | Versin | Secant | Cotan | Tan | Cosec | Covers | Sine | Deg. | Min. |

From 45° to 60° read from bottom of table upwards.

## TABLE 21. LOGARITHMIC TRIGONOMETRIC FUNCTIONS *

| Deg. | Sine | Cosec | Versin | Tangent | Cotan | Covers | Secant | Cosine | Deg |
|---|---|---|---|---|---|---|---|---|---|
| 0 | $-\infty$ | $+\infty$ | $-\infty$ | $-\infty$ | $+\infty$ | 10.00000 | 10.00000 | 10.00000 | 90 |
| 1 | 8.24186 | 11.75814 | 6.18271 | 8.24192 | 11.75808 | 9.99235 | 10.00007 | 9.99993 | 89 |
| 2 | 8.54282 | 11.45718 | 6.78474 | 8.54308 | 11.45692 | 9.98457 | 10.00026 | 9.99974 | 88 |
| 3 | 8.71880 | 11.28120 | 7.13687 | 8.71940 | 11.28060 | 9.97665 | 10.00060 | 9.99940 | 87 |
| 4 | 8.84358 | 11.15642 | 7.38667 | 8.84464 | 11.15536 | 9.96860 | 10.00106 | 9.99894 | 86 |
| 5 | 8.94030 | 11.05970 | 7.58039 | 8.94195 | 11.05805 | 9.96040 | 10.00166 | 9.99834 | 85 |
| 6 | 9.01923 | 10.98077 | 7.73863 | 9.02162 | 10.97838 | 9.95205 | 10.00239 | 9.99761 | 84 |
| 7 | 9.08589 | 10.91411 | 7.87238 | 9.08914 | 10.91086 | 9.94356 | 10.00325 | 9.99675 | 83 |
| 8 | 9.14356 | 10.85644 | 7.98820 | 9.14780 | 10.85220 | 9.93492 | 10.00425 | 9.99575 | 82 |
| 9 | 9.19433 | 10.80567 | 8.09032 | 9.19971 | 10.80029 | 9.92612 | 10.00538 | 9.99462 | 81 |
| 10 | 9.23967 | 10.76033 | 8.18162 | 9.24632 | 10.75368 | 9.91717 | 10.00665 | 9.99335 | 80 |
| 11 | 9.28060 | 10.71940 | 8.26418 | 9.28865 | 10.71135 | 9.90805 | 10.00805 | 9.99195 | 79 |
| 12 | 9.31788 | 10.68212 | 8.33950 | 9.32747 | 10.67253 | 9.89877 | 10.00960 | 9.99040 | 78 |
| 13 | 9.35209 | 10.64791 | 8.40875 | 9.36336 | 10.63664 | 9.88933 | 10.01128 | 9.98872 | 77 |
| 14 | 9.38368 | 10.61632 | 8.47282 | 9.39677 | 10.60323 | 9.87971 | 10.01310 | 9.98690 | 76 |
| 15 | 9.41300 | 10.58700 | 8.53243 | 9.42805 | 10.57195 | 9.86992 | 10.01506 | 9.98494 | 75 |
| 16 | 9.44034 | 10.55966 | 8.58814 | 9.45750 | 10.54250 | 9.85996 | 10.01716 | 9.98284 | 74 |
| 17 | 9.46594 | 10.53406 | 8.64043 | 9.48534 | 10.51466 | 9.84981 | 10.01940 | 9.98060 | 73 |
| 18 | 9.48998 | 10.51002 | 8.68969 | 9.51178 | 10.48822 | 9.83947 | 10.02179 | 9.97821 | 72 |
| 19 | 9.51264 | 10.48736 | 8.73625 | 9.53697 | 10.46303 | 9.82894 | 10.02433 | 9.97567 | 71 |
| 20 | 9.53405 | 10.46595 | 8.78037 | 9.56107 | 10.43893 | 9.81821 | 10.02701 | 9.97299 | 70 |
| 21 | 9.55433 | 10.44567 | 8.82230 | 9.58418 | 10.41582 | 9.80729 | 10.02985 | 9.97015 | 69 |
| 22 | 9.57358 | 10.42642 | 8.86223 | 9.60641 | 10.39359 | 9.79615 | 10.03283 | 9.96717 | 68 |
| 23 | 9.59188 | 10.40812 | 8.90034 | 9.62785 | 10.37215 | 9.78481 | 10.03597 | 9.96403 | 67 |
| 24 | 9.60931 | 10.39069 | 8.93679 | 9.64858 | 10.35142 | 9.77325 | 10.03927 | 9.96073 | 66 |
| 25 | 9.62595 | 10.37405 | 8.97170 | 9.66867 | 10.33133 | 9.76146 | 10.04272 | 9.95728 | 65 |
| 26 | 9.64184 | 10.35816 | 9.00521 | 9.68818 | 10.31182 | 9.74945 | 10.04634 | 9.95366 | 64 |
| 27 | 9.65705 | 10.34295 | 9.03740 | 9.70717 | 10.29283 | 9.73720 | 10.05012 | 9.94988 | 63 |
| 28 | 9.67161 | 10.32839 | 9.06838 | 9.72567 | 10.27433 | 9.72471 | 10.05407 | 9.94593 | 62 |
| 29 | 9.68557 | 10.31443 | 9.09823 | 9.74375 | 10.25625 | 9.71197 | 10.05818 | 9.94182 | 61 |
| 30 | 9.69897 | 10.30103 | 9.12702 | 9.76144 | 10.23856 | 9.69897 | 10.06247 | 9.93753 | 60 |
| 31 | 9.71184 | 10.28816 | 9.15483 | 9.77877 | 10.22123 | 9.68571 | 10.06693 | 9.93307 | 59 |
| 32 | 9.72421 | 10.27579 | 9.18171 | 9.79579 | 10.20421 | 9.67217 | 10.07158 | 9.92842 | 58 |
| 33 | 9.73611 | 10.26389 | 9.20771 | 9.81252 | 10.18748 | 9.65836 | 10.07641 | 9.92359 | 57 |
| 34 | 9.74756 | 10.25244 | 9.23290 | 9.82899 | 10.17101 | 9.64425 | 10.08143 | 9.91857 | 56 |
| 35 | 9.75859 | 10.24141 | 9.25731 | 9.84523 | 10.15477 | 9.62984 | 10.08664 | 9.91336 | 55 |
| 36 | 9.76922 | 10.23078 | 9.28099 | 9.86126 | 10.13874 | 9.61512 | 10.09204 | 9.90796 | 54 |
| 37 | 9.77946 | 10.22054 | 9.30398 | 9.87711 | 10.12289 | 9.60008 | 10.09765 | 9.90235 | 53 |
| 38 | 9.78934 | 10.21066 | 9.32631 | 9.89281 | 10.10719 | 9.58471 | 10.10347 | 9.89653 | 52 |
| 39 | 9.79887 | 10.20113 | 9.34802 | 9.90837 | 10.09163 | 9.56900 | 10.10950 | 9.89050 | 51 |
| 40 | 9.80807 | 10.19193 | 9.36913 | 9.92381 | 10.07619 | 9.55293 | 10.11575 | 9.88425 | 50 |
| 41 | 9.81694 | 10.18306 | 9.38968 | 9.93916 | 10.06084 | 9.53648 | 10.12222 | 9.87778 | 49 |
| 42 | 9.82551 | 10.17449 | 9.40969 | 9.95444 | 10.04556 | 9.51966 | 10.12893 | 9.87107 | 48 |
| 43 | 9.83378 | 10.16622 | 9.42918 | 9.96966 | 10.03034 | 9.50243 | 10.13587 | 9.86413 | 47 |
| 44 | 9.84177 | 10.15823 | 9.44818 | 9.98484 | 10.01516 | 9.48479 | 10.14307 | 9.85693 | 46 |
| 45 | 9.84949 | 10.15052 | 9.46671 | 10.00000 | 10.00000 | 9.46671 | 10.15052 | 9.84949 | 45 |
| | Cosine | Secant | Covers | Cotan | Tangent | Versin | Cosec | Sine | |

**From 45° to 90° read from bottom of table upwards.**

* *From Kent, Mechanical Engineers' Handbook, Power Volume, John Wiley & Sons.*

## TABLE 22. MINUTES INTO DECIMALS OF A DEGREE *

| ′ | 0″ | 10″ | 15″ | 20″ | 30″ | 40″ | 45″ | 50″ | ′ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | .00000 | .00278 | .00417 | .00556 | .00833 | .01111 | .01250 | .01389 | 0 |
| 1 | .01667 | .01944 | .02083 | .02222 | .02500 | .02778 | .02917 | .03055 | 1 |
| 2 | .03333 | .03611 | .03750 | .03889 | .04167 | .04444 | .04583 | .04722 | 2 |
| 3 | .05000 | .05278 | .05417 | .05556 | .05833 | .06111 | .06250 | .06389 | 3 |
| 4 | .06667 | .06944 | .07083 | .07222 | .07500 | .07778 | .07917 | .08056 | 4 |
| 5 | .08333 | .08611 | .08750 | .08889 | .09167 | .09444 | .09583 | .09722 | 5 |
| 6 | .10000 | .10278 | .10417 | .10556 | .10833 | .11111 | .11250 | .11389 | 6 |
| 7 | .11667 | .11944 | .12083 | .12222 | .12500 | .12778 | .12917 | .13056 | 7 |
| 8 | .13333 | .13611 | .13750 | .13889 | .14167 | .14444 | .14583 | .14722 | 8 |
| 9 | .15000 | .15278 | .15417 | .15556 | .15833 | .16111 | .16250 | .16389 | 9 |
| 10 | .16667 | .16944 | .17083 | .17222 | .17500 | .17778 | .17917 | .18056 | 10 |
| 11 | .18333 | .18611 | .18750 | .18889 | .19167 | .19444 | .19583 | .19722 | 11 |
| 12 | .20000 | .20278 | .20417 | .20556 | .20833 | .21111 | .21250 | .21389 | 12 |
| 13 | .21667 | .21944 | .22083 | .22222 | .22500 | .22778 | .22917 | .23056 | 13 |
| 14 | .23333 | .23611 | .23750 | .23889 | .24167 | .24444 | .24583 | .24722 | 14 |
| 15 | .25000 | .25278 | .25417 | .25556 | .25833 | .26111 | .26250 | .26389 | 15 |
| 16 | .26667 | .26944 | .27083 | .27222 | .27500 | .27778 | .27917 | .28056 | 16 |
| 17 | .28333 | .28611 | .28750 | .28889 | .29167 | .29444 | .29583 | .29722 | 17 |
| 18 | .30000 | .30278 | .30417 | .30556 | .30833 | .31111 | .31250 | .31389 | 18 |
| 19 | .31667 | .31944 | .32083 | .32222 | .32500 | .32778 | .32917 | .33056 | 19 |
| 20 | .33333 | .33611 | .33750 | .33889 | .34167 | .34444 | .34583 | .34722 | 20 |
| 21 | .35000 | .35278 | .35417 | .35556 | .35833 | .36111 | .36250 | .36389 | 21 |
| 22 | .36667 | .36944 | .37083 | .37222 | .37500 | .37778 | .37917 | .38056 | 22 |
| 23 | 38333 | .38611 | .38750 | .38889 | .39167 | .39444 | .39583 | .39722 | 23 |
| 24 | .40000 | .40278 | .40417 | .40556 | .40833 | .41111 | .41250 | .41389 | 24 |
| 25 | .41667 | .41944 | .42083 | .42222 | .42500 | .42778 | .42917 | .43056 | 25 |
| 26 | .43333 | .43611 | .43750 | .43889 | .44167 | .44444 | .44583 | .44722 | 26 |
| 27 | .45000 | .45278 | .45417 | .45556 | .45833 | .46111 | .46250 | .46389 | 27 |
| 28 | .46667 | .46944 | .47083 | .47222 | .47500 | .47778 | .47917 | .48056 | 28 |
| 29 | .48333 | .48611 | .48750 | .48889 | .49167 | .49444 | .49583 | .49722 | 29 |
| 30 | .50000 | .50278 | .50417 | .50556 | .50833 | .51111 | .51250 | .51389 | 30 |
| 31 | .51667 | .51944 | .52083 | .52222 | .52500 | .52778 | .52917 | .53056 | 31 |
| 32 | .53333 | .53611 | .53750 | .53889 | .54167 | .54444 | .54583 | .54722 | 32 |
| 33 | .55000 | .55278 | .55417 | .55556 | .55833 | .56111 | .56250 | .56389 | 33 |
| 34 | .56667 | .56944 | .57083 | .57222 | .57500 | .57778 | .57917 | .58056 | 34 |
| 35 | .58333 | .58611 | .58750 | .58889 | .59167 | .59444 | .59583 | .59722 | 35 |
| 36 | .60000 | .60278 | .60417 | .60556 | .60833 | .61111 | .61250 | .61389 | 36 |
| 37 | .61667 | .61944 | .62083 | .62222 | .62500 | .62778 | .62917 | .63056 | 37 |
| 38 | .63333 | .63611 | .63750 | .63889 | .64167 | .64444 | .64583 | .64722 | 38 |
| 39 | .65000 | .65278 | .65417 | .65556 | .65833 | .66111 | .66250 | .66389 | 39 |
| 40 | .66667 | .66944 | .67083 | .67222 | .67500 | .67778 | .67917 | .68056 | 40 |
| 41 | .68333 | .68611 | .68750 | .68889 | .69167 | .69444 | .69583 | .69722 | 41 |
| 42 | .70000 | .70278 | .70417 | .70556 | .70833 | .71111 | .71250 | .71389 | 42 |
| 43 | .71667 | .71944 | .72083 | .72222 | .72500 | .72778 | .72917 | .73056 | 43 |
| 44 | .73333 | .73611 | .73750 | .73889 | .74167 | .74444 | .74583 | .74722 | 44 |
| 45 | .75000 | .75278 | .75417 | .75556 | .75833 | .76111 | .76250 | .76389 | 45 |
| 46 | .76667 | .76944 | .77083 | .77222 | .77500 | .77778 | .77917 | .78056 | 46 |
| 47 | .78333 | .78611 | .78750 | .78889 | .79167 | .79444 | .79583 | .79722 | 47 |
| 48 | .80000 | .80278 | .80417 | .80556 | .80833 | .81111 | .81250 | .81389 | 48 |
| 49 | .81667 | .81944 | .82083 | .82222 | .82500 | .82778 | .82917 | .83056 | 49 |
| 50 | .83333 | .83611 | .83750 | .83889 | .84167 | .84444 | .84583 | .84722 | 50 |
| 51 | .85000 | .85278 | .85417 | .85556 | .85833 | 86111 | .86250 | .86389 | 51 |
| 52 | .86667 | .86944 | .87083 | .87222 | .87500 | .87778 | .87917 | .88056 | 52 |
| 53 | .88333 | .88611 | .88750 | .88889 | .89167 | .89444 | .89583 | .89722 | 53 |
| 54 | .90000 | .90278 | .90417 | .90556 | .90833 | .91111 | .91250 | .91389 | 54 |
| 55 | .91667 | .91944 | .92083 | .92222 | .92500 | .92778 | .92917 | .93056 | 55 |
| 56 | .93333 | .93611 | .93750 | .93889 | .94167 | .94444 | .94583 | .94722 | 56 |
| 57 | .95000 | .95278 | .95417 | .95556 | .95833 | .96111 | .96250 | .96389 | 57 |
| 58 | .96667 | .96944 | .97083 | .97222 | .97500 | .97778 | .97917 | .98056 | 58 |
| 59 | .98333 | .98611 | .98750 | .98889 | .99167 | .99444 | .99583 | .99722 | 59 |
| ′ | 0″ | 10″ | 15″ | 20″ | 30″ | 40″ | 45″ | 50″ | ′ |

* *From Ives, Seven Place Natural Trigonometric Functions, John Wiley & Sons.*

# TABLE 23. LOGARITHMS OF NUMBERS *

| n | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 00000 | 00432 | 00860 | 01284 | 01703 | 02119 | 02531 | 02938 | 03342 | 03743 |
| 11 | 04139 | 04532 | 04922 | 05308 | 05690 | 06070 | 06446 | 06819 | 07188 | 07555 |
| 12 | 07918 | 08279 | 08636 | 08991 | 09342 | 09691 | 10037 | 10380 | 10721 | 11059 |
| 13 | 11394 | 11727 | 12057 | 12385 | 12710 | 13033 | 13354 | 13672 | 13988 | 14301 |
| 14 | 14613 | 14922 | 15229 | 15534 | 15836 | 16137 | 16435 | 16732 | 17026 | 17319 |
| 15 | 17609 | 17898 | 18184 | 18469 | 18752 | 19033 | 19312 | 19590 | 19866 | 20140 |
| 16 | 20412 | 20683 | 20952 | 21219 | 21484 | 21748 | 22011 | 22272 | 22531 | 22789 |
| 17 | 23045 | 23300 | 23553 | 23805 | 24055 | 24304 | 24551 | 24797 | 25042 | 25285 |
| 18 | 25527 | 25768 | 26007 | 26245 | 26482 | 26717 | 26951 | 27184 | 27416 | 27646 |
| 19 | 27875 | 28103 | 28330 | 28556 | 28780 | 29003 | 29226 | 29447 | 29667 | 29885 |
| 20 | 30103 | 30320 | 30535 | 30750 | 30963 | 31175 | 31387 | 31597 | 31806 | 32015 |
| 21 | 32222 | 32428 | 32634 | 32838 | 33041 | 33244 | 33445 | 33646 | 33846 | 34044 |
| 22 | 34242 | 34439 | 34635 | 34830 | 35025 | 35218 | 35411 | 35603 | 35793 | 35984 |
| 23 | 36173 | 36361 | 36549 | 36736 | 36922 | 37107 | 37291 | 37475 | 37658 | 37840 |
| 24 | 38021 | 38202 | 38382 | 38561 | 38739 | 38917 | 39094 | 39270 | 39445 | 39620 |
| 25 | 39794 | 39967 | 40140 | 40312 | 40483 | 40654 | 40824 | 40993 | 41162 | 41330 |
| 26 | 41497 | 41664 | 41830 | 41996 | 42160 | 42325 | 42488 | 42651 | 42813 | 42975 |
| 27 | 43136 | 43297 | 43457 | 43616 | 43775 | 43933 | 44091 | 44248 | 44404 | 44560 |
| 28 | 44716 | 44871 | 45025 | 45179 | 45332 | 45484 | 45637 | 45788 | 45939 | 46090 |
| 29 | 46240 | 46389 | 46538 | 46687 | 46835 | 46982 | 47129 | 47276 | 47422 | 47567 |
| 30 | 47712 | 47857 | 48001 | 48144 | 48287 | 48430 | 48572 | 48714 | 48855 | 48996 |
| 31 | 49136 | 49276 | 49415 | 49554 | 49693 | 49831 | 49969 | 50106 | 50243 | 50379 |
| 32 | 50515 | 50651 | 50786 | 50920 | 51055 | 51188 | 51322 | 51455 | 51587 | 51720 |
| 33 | 51851 | 51983 | 52114 | 52244 | 52375 | 52504 | 52634 | 52763 | 52892 | 53020 |
| 34 | 53148 | 53275 | 53403 | 53529 | 53656 | 53782 | 53908 | 54033 | 54158 | 54283 |
| 35 | 54407 | 54531 | 54654 | 54777 | 54900 | 55023 | 55145 | 55267 | 55388 | 55509 |
| 36 | 55630 | 55751 | 55871 | 55991 | 56110 | 56229 | 56348 | 56467 | 56585 | 56703 |
| 37 | 56820 | 56937 | 57054 | 57171 | 57287 | 57403 | 57519 | 57634 | 57749 | 57864 |
| 38 | 57978 | 58092 | 58206 | 58320 | 58433 | 58546 | 58659 | 58771 | 58883 | 58995 |
| 39 | 59106 | 59218 | 59329 | 59439 | 59550 | 59660 | 59770 | 59879 | 59988 | 60097 |
| 40 | 60206 | 60314 | 60423 | 60531 | 60638 | 60746 | 60853 | 60959 | 61066 | 61172 |
| 41 | 61278 | 61384 | 61490 | 61595 | 61700 | 61805 | 61909 | 62014 | 62118 | 62221 |
| 42 | 62325 | 62428 | 62531 | 62634 | 62737 | 62839 | 62941 | 63043 | 63144 | 63246 |
| 43 | 63347 | 63448 | 63548 | 63649 | 63749 | 63849 | 63949 | 64048 | 64147 | 64246 |
| 44 | 64345 | 64444 | 64542 | 64640 | 64738 | 64836 | 64933 | 65031 | 65128 | 65225 |
| 45 | 65321 | 65418 | 65514 | 65610 | 65706 | 65801 | 65896 | 65992 | 66087 | 66181 |
| 46 | 66276 | 66370 | 66464 | 66558 | 66652 | 66745 | 66839 | 66932 | 67025 | 67117 |
| 47 | 67210 | 67302 | 67394 | 67486 | 67578 | 67669 | 67761 | 67852 | 67943 | 68034 |
| 48 | 68124 | 68215 | 68305 | 68395 | 68485 | 68574 | 68664 | 68753 | 68842 | 68931 |
| 49 | 69020 | 69108 | 69197 | 69285 | 69373 | 69461 | 69548 | 69636 | 69723 | 69810 |
| 50 | 69897 | 69984 | 70070 | 70157 | 70243 | 70329 | 70415 | 70501 | 70586 | 70672 |
| 51 | 70757 | 70842 | 70927 | 71012 | 71096 | 71181 | 71265 | 71349 | 71433 | 71517 |
| 52 | 71600 | 71684 | 71767 | 71850 | 71933 | 72016 | 72099 | 72181 | 72263 | 72346 |
| 53 | 72428 | 72509 | 72591 | 72673 | 72754 | 72835 | 72916 | 72997 | 73078 | 73159 |
| 54 | 73239 | 73320 | 73400 | 73480 | 73560 | 73640 | 73719 | 73799 | 73878 | 73957 |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

* *From American Civil Engineers' Handbook by Merriam and Wiggin, John Wiley & Sons.*

| n | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 74036 | 74115 | 74194 | 74273 | 74351 | 74429 | 74507 | 74586 | 74663 | 74741 |
| 56 | 74819 | 74896 | 74974 | 75051 | 75128 | 75205 | 75282 | 75358 | 75435 | 75511 |
| 57 | 75587 | 75664 | 75740 | 75815 | 75891 | 75967 | 76042 | 76118 | 76193 | 76268 |
| 58 | 76343 | 76418 | 76492 | 76567 | 76641 | 76716 | 76790 | 76864 | 76938 | 77012 |
| 59 | 77085 | 77159 | 77232 | 77305 | 77379 | 77452 | 77525 | 77597 | 77670 | 77743 |
| 60 | 77815 | 77887 | 77960 | 78032 | 78104 | 78176 | 78247 | 78319 | 78390 | 78462 |
| 61 | 78533 | 78604 | 78675 | 78746 | 78817 | 78888 | 78958 | 79029 | 79099 | 79169 |
| 62 | 79239 | 79309 | 79379 | 79449 | 79518 | 79588 | 79657 | 79727 | 79796 | 79865 |
| 63 | 79934 | 80003 | 80072 | 80140 | 80209 | 80277 | 80346 | 80414 | 80482 | 80550 |
| 64 | 80618 | 80686 | 80754 | 80821 | 80889 | 80956 | 81023 | 81090 | 81158 | 81224 |
| 65 | 81291 | 81358 | 81425 | 81491 | 81558 | 81624 | 81690 | 81757 | 81823 | 81889 |
| 66 | 81954 | 82020 | 82086 | 82151 | 82217 | 82282 | 82347 | 82413 | 82478 | 82543 |
| 67 | 82607 | 82672 | 82737 | 82802 | 82866 | 82930 | 82995 | 83059 | 83123 | 83187 |
| 68 | 83251 | 83315 | 83378 | 83442 | 83506 | 83569 | 83632 | 83696 | 83759 | 83822 |
| 69 | 83885 | 83948 | 84011 | 84073 | 84136 | 84198 | 84261 | 84323 | 84386 | 84448 |
| 70 | 84510 | 84572 | 84634 | 84696 | 84757 | 84819 | 84880 | 84942 | 85003 | 85065 |
| 71 | 85126 | 85187 | 85248 | 85309 | 85370 | 85431 | 85491 | 85552 | 85612 | 85673 |
| 72 | 85733 | 85794 | 85854 | 85914 | 85974 | 86034 | 86094 | 86153 | 86213 | 86273 |
| 73 | 86332 | 86392 | 86451 | 86510 | 86570 | 86629 | 86688 | 86747 | 86806 | 86864 |
| 74 | 86923 | 86982 | 87040 | 87099 | 87157 | 87216 | 87274 | 87332 | 87390 | 87448 |
| 75 | 87506 | 87564 | 87622 | 87679 | 87737 | 87795 | 87852 | 87910 | 87967 | 88024 |
| 76 | 88081 | 88138 | 88195 | 88252 | 88309 | 88366 | 88423 | 88480 | 88536 | 88593 |
| 77 | 88649 | 88705 | 88762 | 88818 | 88874 | 88930 | 88986 | 89042 | 89098 | 89154 |
| 78 | 89209 | 89265 | 89321 | 89376 | 89432 | 89487 | 89542 | 89597 | 89653 | 89708 |
| 79 | 89763 | 89818 | 89873 | 89927 | 89982 | 90037 | 90091 | 90146 | 90200 | 90255 |
| 80 | 90309 | 90363 | 90417 | 90472 | 90526 | 90580 | 90634 | 90687 | 90741 | 90795 |
| 81 | 90849 | 90902 | 90956 | 91009 | 91062 | 91116 | 91169 | 91222 | 91275 | 91328 |
| 82 | 91381 | 91434 | 91487 | 91540 | 91593 | 91645 | 91698 | 91751 | 91803 | 91855 |
| 83 | 91908 | 91960 | 92012 | 92065 | 92117 | 92169 | 92221 | 92273 | 92324 | 92376 |
| 84 | 92428 | 92480 | 92531 | 92583 | 92634 | 92686 | 92737 | 92788 | 92840 | 92891 |
| 85 | 92942 | 92993 | 93044 | 93095 | 93146 | 93197 | 93247 | 93298 | 93349 | 93399 |
| 86 | 93450 | 93500 | 93551 | 93601 | 93651 | 93702 | 93752 | 93802 | 93852 | 93902 |
| 87 | 93952 | 94002 | 94052 | 94101 | 94151 | 94201 | 94250 | 94300 | 94349 | 94399 |
| 88 | 94448 | 94498 | 94547 | 94596 | 94645 | 94694 | 94743 | 94792 | 94841 | 94890 |
| 89 | 94939 | 94988 | 95036 | 95085 | 95134 | 95182 | 95231 | 95279 | 95328 | 95376 |
| 90 | 95424 | 95472 | 95521 | 95569 | 95617 | 95665 | 95713 | 95761 | 95809 | 95856 |
| 91 | 95904 | 95952 | 95999 | 96047 | 96095 | 96142 | 96190 | 96237 | 96284 | 96332 |
| 92 | 96379 | 96426 | 96473 | 96520 | 96567 | 96614 | 96661 | 96708 | 96755 | 96802 |
| 93 | 96848 | 96895 | 96942 | 96988 | 97035 | 97081 | 97128 | 97174 | 97220 | 97267 |
| 94 | 97313 | 97359 | 97405 | 97451 | 97497 | 97543 | 97589 | 97635 | 97681 | 97727 |
| 95 | 97772 | 97818 | 97864 | 97909 | 97955 | 98000 | 98046 | 98091 | 98137 | 98182 |
| 96 | 98227 | 98272 | 98318 | 98363 | 98408 | 98453 | 98498 | 98543 | 98588 | 98632 |
| 97 | 98677 | 98722 | 98767 | 98811 | 98856 | 98900 | 98945 | 98989 | 99034 | 99078 |
| 98 | 99123 | 99167 | 99211 | 99255 | 99300 | 99344 | 99388 | 99432 | 99476 | 99520 |
| 99 | 99564 | 99607 | 99651 | 99695 | 99739 | 99782 | 99826 | 99870 | 99913 | 99957 |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

## TABLE 24. DECIMAL EQUIVALENTS OF COMMON FRACTIONS *

The given decimals are the parts of inches corresponding to fraction of inches in first column; also, the parts of feet for the fraction of inches in third column.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0052 | 1/16 | | 0.2552 | 3 1/16 | | 0.5052 | 6 1/16 | | 0.7552 | 9 1/16 |
| | 0.0104 | 1/8 | | 0.2604 | 3 1/8 | | 0.5104 | 6 1/8 | | 0.7604 | 9 1/8 |
| 1/64 | 0.015625 | 3/16 | 17/64 | 0.265625 | 3 3/16 | 33/64 | 0.515625 | 6 3/16 | 49/64 | 0.765625 | 9 3/16 |
| | 0.0208 | 1/4 | | 0.2708 | 3 1/4 | | 0.5208 | 6 1/4 | | 0.7708 | 9 1/4 |
| | 0.0260 | 5/16 | | 0.2760 | 3 5/16 | | 0.5260 | 6 5/16 | | 0.7760 | 9 5/16 |
| 1/32 | 0.03125 | 3/8 | 9/32 | 0.28125 | 3 3/8 | 17/32 | 0.53125 | 6 3/8 | 25/32 | 0.78125 | 9 3/8 |
| | 0.0364 | 7/16 | | 0.2865 | 3 7/16 | | 0.5364 | 6 7/16 | | 0.7865 | 9 7/16 |
| | 0.0417 | 1/2 | | 0.2917 | 3 1/2 | | 0.5417 | 6 1/2 | | 0.7917 | 9 1/2 |
| 3/64 | 0.046875 | 9/16 | 19/64 | 0.296875 | 3 9/16 | 35/64 | 0.546875 | 6 9/16 | 51/64 | 0.796875 | 9 9/16 |
| | 0.0521 | 5/8 | | 0.3021 | 3 5/8 | | 0.5521 | 6 5/8 | | 0.8021 | 9 5/8 |
| | 0.0573 | 11/16 | | 0.3073 | 3 11/16 | | 0.5573 | 6 11/16 | | 0.8073 | 9 11/16 |
| 1/16 | 0.0625 | 3/4 | 5/16 | 0.3125 | 3 3/4 | 9/16 | 0.5625 | 6 3/4 | 13/16 | 0.8125 | 9 3/4 |
| | 0.0677 | 13/16 | | 0.3177 | 3 13/16 | | 0.5677 | 6 13/16 | | 0.8177 | 9 13/16 |
| | 0.0729 | 7/8 | | 0.3229 | 3 7/8 | | 0.5729 | 6 7/8 | | 0.8229 | 9 7/8 |
| 5/64 | 0.078125 | 15/16 | 21/64 | 0.328125 | 3 15/16 | 37/64 | 0.578125 | 6 15/16 | 53/64 | 0.828125 | 9 15/16 |
| | 0.0833 | 1 | | 0.3333 | 4 | | 0.5833 | 7 | | 0.8333 | 10 |
| | 0.0885 | 1 1/16 | | 0.3385 | 4 1/16 | | 0.5885 | 7 1/16 | | 0.8385 | 10 1/16 |
| 3/32 | 0.09375 | 1 1/8 | 11/32 | 0.34375 | 4 1/8 | 19/32 | 0.59375 | 7 1/8 | 27/32 | 0.84375 | 10 1/8 |
| | 0.0990 | 1 3/16 | | 0.3490 | 4 3/16 | | 0.5990 | 7 3/16 | | 0.8490 | 10 3/16 |
| | 0.1042 | 1 1/4 | | 0.3542 | 4 1/4 | | 0.6042 | 7 1/4 | | 0.8542 | 10 1/4 |
| 7/64 | 0.109375 | 1 5/16 | 23/64 | 0.359375 | 4 5/16 | 39/64 | 0.609375 | 7 5/16 | 55/64 | 0.859375 | 10 5/16 |
| | 0.1146 | 1 3/8 | | 0.3646 | 4 3/8 | | 0.6146 | 7 3/8 | | 0.8646 | 10 3/8 |
| | 0.1198 | 1 7/16 | | 0.3698 | 4 7/16 | | 0.6198 | 7 7/16 | | 0.8698 | 10 7/16 |
| 1/8 | 0.1250 | 1 1/2 | 3/8 | 0.3750 | 4 1/2 | 5/8 | 0.6250 | 7 1/2 | 7/8 | 0.8750 | 10 1/2 |
| | 0.1302 | 1 9/16 | | 0.3802 | 4 9/16 | | 0.6302 | 7 9/16 | | 0.8802 | 10 9/16 |
| | 0.1354 | 1 5/8 | | 0.3854 | 4 5/8 | | 0.6354 | 7 5/8 | | 0.8854 | 10 5/8 |
| 9/64 | 0.140625 | 1 11/16 | 25/64 | 0.390625 | 4 11/16 | 41/64 | 0.640625 | 7 11/16 | 57/64 | 0.890625 | 10 11/16 |
| | 0.1458 | 1 3/4 | | 0.3958 | 4 3/4 | | 0.6458 | 7 3/4 | | 0.8958 | 10 3/4 |
| | 0.1510 | 1 13/16 | | 0.4010 | 4 13/16 | | 0.6510 | 7 13/16 | | 0.9010 | 10 13/16 |
| 5/32 | 0.15625 | 1 7/8 | 13/32 | 0.40625 | 4 7/8 | 21/32 | 0.65625 | 7 7/8 | 29/32 | 0.90625 | 10 7/8 |
| | 0.1615 | 1 15/16 | | 0.4114 | 4 15/16 | | 0.6615 | 7 15/16 | | 0.9115 | 10 15/16 |
| | 0.1667 | 2 | | 0.4167 | 5 | | 0.6667 | 8 | | 0.9167 | 11 |
| 11/64 | 0.171875 | 2 1/16 | 27/64 | 0.421875 | 5 1/16 | 43/64 | 0.671875 | 8 1/16 | 59/64 | 0.921875 | 11 1/16 |
| | 0.1771 | 2 1/8 | | 0.4271 | 5 1/8 | | 0.6771 | 8 1/8 | | 0.9271 | 11 1/8 |
| | 0.1823 | 2 3/16 | | 0.4323 | 5 3/16 | | 0.6823 | 8 3/16 | | 0.9323 | 11 3/16 |
| 3/16 | 0.1875 | 2 1/4 | 7/16 | 0.4375 | 5 1/4 | 11/16 | 0.6875 | 8 1/4 | 15/16 | 0.9375 | 11 1/4 |
| | 0.1927 | 2 5/16 | | 0.4427 | 5 5/16 | | 0.6927 | 8 5/16 | | 0.9427 | 11 5/16 |
| | 0.1979 | 2 3/8 | | 0.4479 | 5 3/8 | | 0.6979 | 8 3/8 | | 0.9479 | 11 3/8 |
| 13/64 | 0.203125 | 2 7/16 | 29/64 | 0.453125 | 5 7/16 | 45/64 | 0.703125 | 8 7/16 | 61/64 | 0.953125 | 11 7/16 |
| | 0.2083 | 2 1/2 | | 0.4583 | 5 1/2 | | 0.7083 | 8 1/2 | | 0.9583 | 11 1/2 |
| | 0.2135 | 2 9/16 | | 0.4635 | 5 9/16 | | 0.7135 | 8 9/16 | | 0.9635 | 11 9/16 |
| 7/32 | 0.21875 | 2 5/8 | 15/32 | 0.46875 | 5 5/8 | 23/32 | 0.71875 | 8 5/8 | 31/32 | 0.96875 | 11 5/8 |
| | 0.2240 | 2 11/16 | | 0.4740 | 5 11/16 | | 0.7240 | 8 11/16 | | 0.9740 | 11 11/16 |
| | 0.2292 | 2 3/4 | | 0.4792 | 5 3/4 | | 0.7292 | 8 3/4 | | 0.9792 | 11 3/4 |
| 15/64 | 0.234375 | 2 13/16 | 31/64 | 0.484375 | 5 13/16 | 47/64 | 0.734375 | 8 13/16 | 63/64 | 0.984375 | 11 13/16 |
| | 0.2395 | 2 7/8 | | 0.4896 | 5 7/8 | | 0.7396 | 8 7/8 | | 0.9896 | 11 7/8 |
| | 0.2448 | 2 15/16 | | 0.4948 | 5 15/16 | | 0.7448 | 8 15/16 | | 0.9948 | 11 15/16 |
| 1/4 | 0.2500 | 3 | 1/2 | 0.5000 | 6 | 3/4 | 0.7500 | 9 | 1 | 1.0000 | 12 |

* *From Peele, Mining Engineers' Handbook, John Wiley & Sons.*

## SURVEYING SIGNALS *

Except for short distances a good system of hand signals between different members of the party makes an efficient means of communication. The number of signals necessary will depend upon the kind of work and the nature of the country. A few of the more common are given below:

**"Right" or "Left."** The arm is extended in the direction of the desired movement, the right arm being extended for a movement to the right and the left arm for a movement to the left. A long, slow, sweeping motion of the hand indicates a long movement; a short, quick motion indicates a short movement. This signal may be given by the transitman in directing the chainman on line, by the leveler in directing the rodman for a turning point, by the chief of the party to any member, or by one chainman to another chainman.

**"All Right."** Both arms are extended horizontally and the forearms waved vertically. The signal may be given by any member of any party.

**"Plumb the Flag" or "Plumb the Rod."** The arm is held vertically and moved in the direction that the flag or rod is to be plumbed. It is given by the transitman or leveler.

**"Give a Foresight."** The instrumentman holds one arm vertically above his head.

**"Establish a Turning Point" or "Set a Hub."** The instrumentman holds one arm above his head and waves it in a circle.

**"Give Line."** The flagman holds the flag horizontally in both hands above his head and brings it down and turns it to a vertical position. If he desires to set a hub, he waves the flag with one end in the ground from side to side.

**"Turning Point" or "Bench Mark."** In profile leveling the rodman holds the rod horizontally above his head and then brings it down on the point.

**"Wave the Rod."** The leveler holds one arm above his head and moves it from side to side.

**"Pick up the Instrument."** Both arms are extended downward and outward, then inward and up, as one would do in grasping the legs of the tripod and shouldering the instrument. It is given by the chief of the party or by the head chainman when the transit is to be moved.

Care should be taken to make the signals so clear that they may be readily understood. Where long sights are taken or where the peculiar color of the background renders hand signals indistinct, colored flags similar to those of railroad trainmen may be used to good advantage. Of course the color should be in contrast with that of the background. Red can be seen very well against snow, and white can be distinguished clearly against the dark green of the forest.

* *From Raymond E. Davis, Manual of Surveying for Field and Office, 1915.*

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